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METHODS AND PLANT
FOR
EXCAVATION AND EMBANKMENT



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METHODS AND PLANT
FOR
EXCAVATION AND EMBANKMENT

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PREFACE

Developments in recent years have brought about a great increase in the ways and means of handling excavation and embankment on a large scale, particularly in the types of excavating machinery. As new machines have been perfected, new methods have developed, until at the present time the designer and construction engineer often face the problem of selecting from the many possible means of handling a specified job that one which will best fit the physical conditions imposed.

The object of the authors of this book has been to gather together, from their own experience and that of others, data regarding the more common types of excavators and methods of handling excavation and embankment construction, and to present this material in an orderly manner so that it may be readily available for the use of engineers interested in such work.

It is hoped, also, that this material may be of use to engineering students in getting a general idea of the problems involved in selecting equipment and methods for important construction jobs.

Much of the material was obtained first hand from experience with particular jobs; this applies particularly to the discussion of dragline excavator operation, hydraulic sluicing, and hydraulic-fill dam construction. In some cases, authorities on certain classes of work have been consulted (as noted in the text), and the discussion presents what is believed to be the best current opinion on such work.

Throughout the text the aim has been to explain methods and describe plant in as simple terms as possible, and no attempt has been made to discuss the technical details of the design of excavating machinery. Such information may be obtained from the manufacturers of the various equipment. The discussions of the various methods of handling excavation and embankment work are followed by short descriptions of actual jobs, with performance records and costs in many cases.

The authors have abstracted many articles from the civil engineering periodicals for use as illustrations of actual construction jobs. Specific references to the publications quoted are given in the text.

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DAYTON, OHIO,
August, 1927.

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METHODS AND PLANT FOR EXCAVATION AND EMBANKMENT

INTRODUCTION

Scope of Discussion.—In this volume the discussion of excavation and embankment methods and plant is confined to the more common types of work, such as are to be met on most construction jobs. No attempt is made to cover the very specialized types, such as tunneling, subway construction, mining by shafts and drifts. This book is in no sense a compilation of important construction jobs. The comparatively few jobs described here were selected for the sole purpose of illustrating the use of certain plant or methods, and not necessarily because of their importance as construction projects.

Method of Presentation.—The method of presenting the material is through a discussion of each of the various types of equipment and plant in some detail, giving general outlines of operations and methods, followed by descriptions of certain jobs as illustrations of practice under actual operating conditions. Where possible, cost data and performance records are cited. In all cases where performance records are given, emphasis is placed on the *average* outputs of the plant rather than the *maximum* quantities. This is done because it is the average everyday performance that counts in the long run, and estimates on new work should be based on such performance rather than on unusually favorable past records. Some “maximum performance” and “least cost” data are given to show what can be done under favorable conditions.

Cost Records.—Cost data are of value in connection with estimates on work only when so presented that the records can be applied to other jobs similar to those for which the data are given. The bare figures of the costs on a job in cents or dollars per cubic

yard are of little value, in themselves, to the man seeking information and guidance. Data as to labor rates, size of job, size of labor force, size and kind of plant, locality of job, etc. are needed in order that cost figures may be intelligently applied to other work. In the following discussion, therefore, cost figures usually are given only when enough data were available to make comparisons possible. Very complete and detailed cost data are presented on dragline excavation and on hydraulic-fill operations. This information was obtained largely from the records of the Miami Conservancy District, as the construction work on that project was so organized that detailed cost records could be secured as the work progressed. Practically all of the major construction operations of the district were handled through its own construction organization, which included a purchasing division, employment department, commissary, etc. Much of the Miami valley work was done during and immediately following the World War, and the effects of labor and material shortages, as well as the intangible effects of war conditions, were naturally reflected in the costs, which are somewhat higher than they would have been under normal conditions. However, these costs are not far out of line for present-day (1927) conditions.

Organization for Construction Work.—Little is said in the following pages about the details of construction organization for the various types of work considered. Naturally these details of personnel, accounting, etc. will vary greatly on each individual job. However, certain recommendations may be made which are applicable to any construction project or contracting organization. Like any business, construction work must be intelligently planned and executed to be done successfully. To accomplish this end, especially on large projects, attention must be given to the selection of capable supervisors, foremen, timekeepers, etc., and each subordinate member of the organization should have a definite idea of his responsibilities and his part in the handling of the job. The interest of the employee in the job is thus secured and retained.

On any project of considerable size a certain amount of field accounting and cost keeping will be necessary in order that wasteful methods may be corrected and that costs of the work may be checked up as the work progresses. Cost keeping can be, and often is, overdone. The simpler the work can be made the better. A multitude of involved forms and charts are not

required to get sufficient data from which to work up costs on an ordinary job. Simple methods make it possible to keep the costs more nearly up to date, which is a great advantage. There should be an accurate daily time record, an account of expenditures for supplies, renewals, repair parts, etc., a check-up of output of the various machines, and a record of repair costs. Unit costs and performance records should be worked up from the field data by some one familiar with the details of the job, and such costs should be checked against total expenditures.

Study of Completed Jobs.—For the man with limited experience in construction work the best way to gain a knowledge of approved and successful methods for handling a job is through the study of reports and descriptions of work similar to that at hand. In the following pages many actual jobs are described to illustrate the methods and plant that have been used to handle the various kinds of work under different conditions. Many more such examples may be found in the technical press, particularly in the civil engineering periodicals, and the readers of this volume are referred to such publications for additional examples of successful applications of various methods for the types of jobs considered.

PART I

CHAPTER I

SIZING UP AN EXCAVATION JOB

As indicated in the introduction, the type of project considered in this discussion will be a job of sufficient size to warrant the use of some plant or equipment other than hand tools. Very specialized excavating jobs, such as tunneling, subway work, etc., will not be discussed.

Before proceeding to the general features involved in sizing up a job and selecting methods and plant for doing it, the distinction between the terms *plant* and *equipment*, as used in this discussion, will be made clear. A construction *plant* is an assembly of the various units of equipment so coordinated that a given piece of work may be handled. The term "equipment" applies to the non-expendable articles of machinery or materials (usually forming parts of the plant) which have a value separate and apart from the plant itself, and are capable of being transferred from plant to plant, or used independently. For example, a derrick set up and ready to work is *plant*. The derrick irons and sticks, the hoists, and the motor or boiler are items of *equipment*.

Given a job of excavation, the more important elements to be considered, before an intelligent decision can be reached regarding methods and plant to carry out the project, are the following (not necessarily in their order of importance):

1. Kind of job, as highway, ditch, stripping work, etc.
2. Size of job, as to quantity and extent.
3. Location of job, geographically and climatically.
4. Kind of material involved, as clay, gravel, rock, etc.
5. Time allowed for completion.
6. Availability and cost of labor.
7. Transportation facilities to job.
8. Requirements as to finish, *i.e.*, amount of fine grading and finishing of slopes, etc.
9. Connection of job with other work, such as dam building, concrete construction, etc.

10. Disposal of waste material.

11. Amount of money available for investment in plant and equipment.

It is evident that the nature of the job should receive first consideration. For instance, if the work to be done is the excavation of a drainage ditch through a wooded, wet area, the choice of plant is at once limited to certain types of excavators; if the job is a stripping operation like that in the coal fields, the choice is limited to certain other types. So, to offer a partial guide to the selection of plant for various kinds of excavating work, the following tabulation has been made, which lists the machines most frequently used for certain classes of work. Of course, special conditions may require the use of other machines or modifications of the types listed for a specific job.

Kind of Work	Type of Excavator
Ditching (timbered land).....	Dipper dredge (dry land or floating), dragline.
Ditching (wet, cleared land).....	Dipper, hydraulic or grapple dredge.
Ditching (small, dry).....	Elevating grader, scrapers, power shovel, dragline.
Road and street grading (earth).....	Power shovel, dragline, elevating grader, scrapers, hydraulic sluicing.
Road and street grading (rock).....	Power shovel, dragline.
Railroad grading (earth or rock).....	Same as for road and street grading.
Levee construction.....	Cableway excavator, power shovel, dragline, elevating grader, scrapers, hydraulic dredge, grapple dredge.
Gravel pits (wet).....	Cableway excavator, ladder or hydraulic dredge, dragline, derricks.
Gravel pits (dry).....	Cableway excavator, power shovel, dragline, derricks.
Stripping.....	Power shovel, dragline, cableway excavator, hydraulic sluicing, scrapers, elevating grader.
Quarrying.....	Power shovel, dragline, derricks.
River channels (wet).....	Dragline; dipper, hydraulic or grapple dredge; cableway excavator.
River channels (dry).....	Dragline, power shovel, cableway excavator, scrapers.

Kind of Work	Type of Excavator
Borrow pits (large).....	Dragline, power shovel, hydraulic sluicing.
Borrow pits (small).....	Elevating grader, scrapers, power shovel, dragline.
Harbors, large canals.....	Dipper, hydraulic, or ladder dredge.
Placer mining.....	Ladder dredge, hydraulic sluicing.
Reclamation by filling.....	Hydraulic dredge, hydraulic sluicing, power shovel and cars, dragline excavator and cars.
Foundations.....	Power shovel, scrapers, dragline.

It may be seen from the above list, that on many classes of jobs a wide choice of plant and method is available. The problem is to select that combination which will best fit a given job. If consideration and thought are given to the eleven elements enumerated above, an intelligent selection should be possible.

The size of the job is an important element. On a road-grading project where the total yardage is small and the work is spread out, a heavy investment in power shovels would not be justified. On the other hand, it would not be economical, ordinarily, to attempt to handle a large borrow-pit excavation, running into hundreds of thousands of cubic yards, with a team and scraper outfit. Of course, on some projects there will be a variety of excavating jobs, and it may be proper to bring in plant and equipment best suited to the general needs and adapt what is on the ground to the various features of the work. In this connection, attention is called to the great adaptability of certain excavating machines—notably the power shovel and dragline excavator.

The location of the work will have a considerable influence on the choice of plant. When power equipment is used, the motive power may be steam, electricity, gasoline, or oil. In certain parts of the country it would be folly to attempt to use any but a steam-operated plant; in other sections, where electric power is available and cheap, electrically driven shovels, dredges, or draglines will be economical. In remote sections, where transportation is difficult and the work is far from railroads, consideration may well be given to the gasoline or Diesel oil-burning engines for primary power on excavating machines. If livestock are to be

used, as on elevating grader or scraper jobs, consideration must be given to the availability of feed and drinking water, and to the climate. Horses, and even mules, cannot work continuously to advantage in extremely hot, dry climates. No matter what method may be used to handle an excavation job, a supply of water will be necessary, and the location and quantity of available water should be determined.

Of course, the selection of plant and method will be influenced to a large extent by the nature of the material to be handled. Certain equipment which can handle earth in a highly satisfactory manner will be of no use whatever in rock excavation. For instance, the elevating grader is often an economical machine to use on road or pit grading, providing the material is of earth or loam, and dry, but when rock is present in any considerable quantity this machine cannot operate satisfactorily. Likewise, in subaqueous work, the hydraulic dredge is a most efficient excavator in mucky, sandy, or even gravelly material, but when rock is present to any extent, the job can be handled best by the dipper or grapple dredge or the dragline excavator. Rock excavation in the dry is handled well by the rugged power shovels or dragline machines. Many excavators, in fact most types, can be used to work gravel deposits in the dry. Perhaps the most satisfactory machines for this work, all things considered, are the slackline cableway outfits, though power shovels and dragline excavators can handle gravel economically, especially when the material is used directly from the pit. Where the gravel is under water, floating dredges or cableways are commonly used. The ladder dredge is particularly well adapted to quantity work of this kind. Under favorable conditions, large jobs of earth and gravel excavation, such as the removal and levelling off of hilly terrain or the excavation of material for dams or large embankments, may be handled economically by hydraulic monitors or "giants."

Before the method of handling a job is definitely planned, consideration should be given to the time element. On practically all construction work a time limit is set for the completion of the job. Given the size, location, and nature of the work, it will not be difficult to decide which of the available methods will handle it best within the time specified for completion. In this connection it should be remembered that it is seldom that as much speed can be made on night work as on the day shift. A

possible exception is on dredging operations, such as river and harbor improvements, which may be handled by self-propelled hydraulic or ladder dredges of the hopper type. Careful planning and constant supervision are necessary on any job of excavation to secure the consistent progress which will insure completion of the work on time. In general, the more men there are on a job the greater will be the need of efficient supervision. Where a team and scraper outfit is handling a grading project constant attention of the foreman is necessary; in a gravel pit where the digging is being done by a slackline cableway plant progress will depend on the constant operation of the machine, but close supervision will not be so necessary to secure results.

The availability and cost of labor for a job are elements requiring careful consideration. Here, too, the problem is greater as the number of men necessary to run the job increases. With the facilities now available in nearly all parts of the country, it should not be difficult to secure complete and authentic information regarding labor rates and supply in the vicinity of any project. On a given job, scarcity of labor will be an influence leading to the use of plant and methods requiring the minimum of men. For example, a levee job in the south, where labor is plentiful and cheap, might be handled economically by a team-and-scraper outfit, while a similar job in the north central states might be done to better advantage by a dragline excavator plant requiring only a small crew to handle the entire work. Of course, consideration should be given to the investment in the plant, which will be a considerable factor if only a single job is contemplated. Most excavating machines have a fairly long life, however, provided they are properly operated and maintained, and the entire cost of a piece of equipment need not be charged to a single job in case further work for the machine, or an opportunity to sell it on completion of the work, can be foreseen.

The facilities for transporting plant and equipment to and from the site of a project should be studied. From the standpoint of quantity and nature of the material, a certain job may seem just fit for a certain type of plant, but if this plant is bulky and heavy and the site of operations is far from a railroad, perhaps in a mountainous section, it may not be practicable to use the plant that seemed so well suited to the job. A study of the situation, in connection with the other elements listed at the beginning of this discussion, will determine the probable best

procedure. Sometimes, on large projects located in remote places, considerations of time involved will influence the selection of plant and method, regardless of accessibility. In other words, it will appear that, even though it may be a costly and tedious job to bring in large units of equipment, the time saved by using such an outfit once it is set up will be worth more in the long run than the additional expense involved in installing such equipment.

The requirements as to the finishing or "polishing up" of a job will have some influence on the selection of equipment, though on a large project it would not pay to eliminate the big, rough excavators just because they could not handle the fine grading. Cheap auxiliary equipment, such as graders or levelers, may be used to handle the finishing. On certain work, such as levee construction, it will often be possible to use an outfit that can place the fill in such a manner that little dressing up will be needed. With proper handling, draglines, power shovels, or cableway excavators can place levee embankments fairly close to line and grade, so that little smoothing off will be necessary.

On large projects, consideration should always be given to the connection of the excavation with other features of the work, and excavation plant and methods should be adopted which will fit in with the other operations. Ditching, road and railroad grading, and often levee work are jobs complete in themselves, but excavations for dams, reservoirs, large buildings, etc. are tied up with other work, such as embankment building, concrete operations, etc. Here again, the adaptable machine is an advantageous piece of equipment.

The ordinary excavation project is not simply a job of digging—the material must be disposed of after it has been excavated. Often it costs more to get rid of the material than it does to dig it. So the preliminary study of every piece of excavating work should include considerations of haul distances, spoil bank areas, grades to and from spoil areas, etc. These considerations may influence the selection of excavating plant, though often conditions may be such that the disposal problem will be the same no matter what type of excavator might be used. Sometimes, under favorable conditions, the mechanical transportation of the material can be eliminated, as by the use of hydraulic sluicing methods or the hydraulic dredge.

Whatever equipment may be selected for a job, the item of plant maintenance should not be overlooked. The first cost of equipment and plant installation is only a part of the total plant cost. Maintenance cost is a considerable item; sometimes, on long jobs, amounting to a large percentage of the first cost of the plant. Cost of dismantling also must be figured in as a part of the whole cost. As an example: an electric dragline excavator, skid and roller mounted, equipped with 100-ft. boom and $3\frac{1}{2}$ -cu. yd. bucket, cost \$31,500 (second-hand) in 1918. This machine was used on channel excavation over a period of several years, working two 10-hr. shifts per day. The cost of supplies, parts, and repairs on this machine for a typical year (1921) amounted to \$11,603, or about 37 per cent of the cost of the machine. Details of the items making up the sum of \$11,603 are given in Table III, Chap. V. A steam dragline, caterpillar mounted, and equipped with 60-ft. boom and 2-cu. yd. bucket, cost \$18,000 (second-hand) in 1918. This machine was used for miscellaneous channel excavation and levee work, and to handle material on a spoil bank. For the year 1921, the cost of supplies, parts and repairs on this machine was \$4,306, or 24 per cent of the first cost of the machine. A dragline machine of the size and type first mentioned above, which cost \$38,600 (new) in 1918, was used to excavate gravel from a borrow pit. It worked two 10-hr. shifts daily. During the period from May to August, inclusive, 1921, the cost of supplies and minor repairs was \$3,678, or $9\frac{1}{2}$ per cent of the first cost of the machine in a 5-month period. Some figures on dismantling and erection costs of dragline excavators are given in Chap. V, and similar information regarding dredges may be found in Chap. VIII.

Once the method of handling a job and the type of plant have been decided upon, it remains to secure the equipment. Some items to be considered in the choice of an excavating machine of a certain type are the following: (1) number of working parts; (2) accessibility for oiling, greasing, fueling, etc.; (3) ruggedness of construction; (4) mobility; (5) erection and dismantling cost and time; (6) first cost and probable depreciation in value; (7) resale value; (8) speed of operation; (9) economy of operation.

There is a certain advantage in choosing for a job of excavation the type of equipment and plant layout that is customary for the particular kind of work. This is especially so where methods have been well standardized. The application and trying out

of unusual methods and plant should be undertaken cautiously and only after due consideration has been given to the usual methods. This is not written to discourage the development of new ideas, but sometimes the engineer or contractor may be influenced by equipment salesmen or by others to attempt a job with an outfit which will not handle the work as efficiently as it might be done by standardized equipment for the particular job.

CHAPTER II

THE SCRAPER

Scrapers of various types have been used for many years for excavation in earth or easily loosened material. Their field of usefulness is varied, but usually is limited to the relatively small jobs, that is, where the yardage is not enough to warrant the installation of power equipment. The three commonly used scrapers are the drag or slip, the wheel, and the fresno types.

DRAG SCRAPERS

Drag scrapers (see Fig. 1) have rated capacities of from $3\frac{1}{2}$ to 7 cu. ft.; however, under working conditions they will carry only



FIG. 1.—Standard drag scraper.

These scrapers usually have a double bottom or a pair of runners on the bottom to reduce wear. They are made in three sizes of from $3\frac{1}{2}$ to $5\frac{1}{2}$ -cu. ft. capacity. (*Photo from Western Wheeled Scraper Company, Aurora, Ill.*)

from 60 to 75 per cent of their rated capacities. They are pulled by two horses or mules, and are operated by the driver who dumps the scraper on the fill. Usually an extra man is used for loading. These scrapers are used in short-haul jobs, such as excavating cellars, construction of small earth or gravel levees, small drainage ditches, making cuts and fills for road work, etc. They can

be used only in dry material, that is, the material must be solid enough to support the teams. The economical limit of haul for drag-scraper work will vary under different conditions, but in general, they can be used efficiently on hauls up to 100 ft., and in some cases up to 200 ft. The latter figure, however, is about the extreme limit for drag scraper work.

DRAG-SCRAPER METHODS AND PERFORMANCE

Except in the softest materials, the first step in starting a drag-scraper excavation job is to loosen the material by plowing. A heavy road plow is best for this. Sometimes a small gasoline tractor can be used economically for pulling the plow. After the material is loosened up a short distance ahead the scrapers can be put to work. On the ordinary job one man should be detailed to load the scrapers as they come into the cut. He should see that they are fully loaded, but as soon as they are full they should not be pulled any farther into the material, as this only throws extra work on the team. The loaded scraper should then be hauled by the shortest path to the dump. Loaded scrapers should always have the right of way over empty ones returning to the cut. The driver dumps the scraper at the place indicated by the foreman. One or more men should be kept on the dump to level up the dumped material; or a small road grader can be used for this purpose if the material is not too soft. Of course, where the dump is simply a spoil bank it will only be necessary to level it off roughly.

The number of scrapers to be used on a given job will be governed by several conditions, chief of which will be the length of haul and the amount of material to be handled. There should be enough scrapers so that the loader is kept busy loading and, at the same time, there should be no lost time at the dump waiting for teams to get out of the way. The output on a drag-scraper job depends very largely on the experience and constant supervision of the foreman. Average outputs for various lengths of haul may be given roughly as follows:

25-ft. haul.....	70 cu. yd. per day
50-ft. haul.....	60 cu. yd. per day
100-ft. haul.....	50 cu. yd. per day

The above figures are for a 10-hr. day, working in loose material.

FRESNO SCRAPERS

The fresno is a modified drag scraper which was developed in the west, but is now used in all parts of the country. It has a long narrow scoop and adjustable runners on each side fastened above the cutting edge of the scoop (see Fig. 2). The fresno is loaded in the same manner as a drag scraper, and is dumped by pushing the dump handle forward, throwing the weight on the runners, and raising the scoop so that the material spills out.

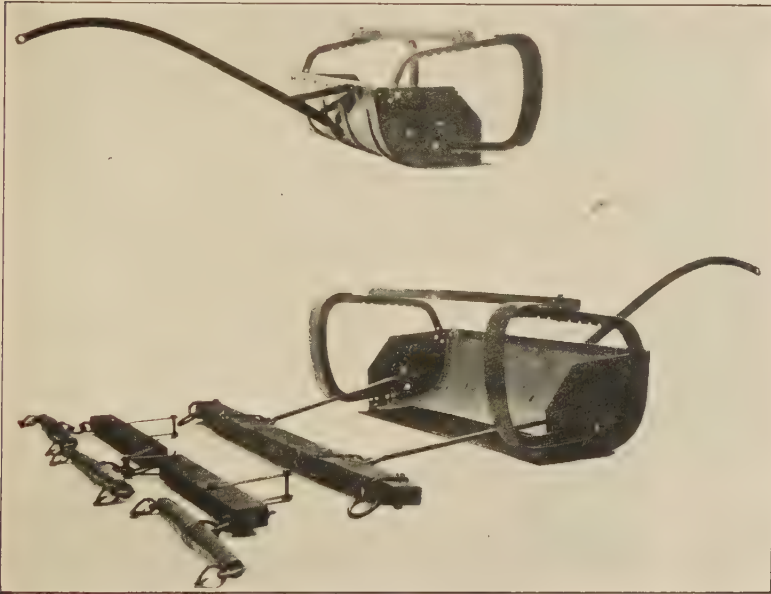


FIG. 2.—Fresno scraper with pull rods and evener.

Scrapers of this type are very efficient in easily dug material, especially on down-hill work. The upper picture shows a rear view of a standard fresno. (Photos from *Western Wheeled Scraper Company*.)

This type of scraper is especially adapted to down-hill work, where large loads can be pushed along by the scraper. Fresnos are made in three sizes as follows:

- No. 1. 5-ft. cutting edge 15 cu. ft. rated capacity.
- No. 2. 4-ft. cutting edge 12 cu. ft. rated capacity.
- No. 3. 3½-ft. cutting edge 10 cu. ft. rated capacity.

As with drag scrapers, the working load is much less than the rated capacity, except on down-hill work. A standard 4-ft. fresno loads about 9 cu. ft. in average material.

Fresnos are usually hauled by a three-mule team, with one driver. No snatch team is used for loading, and usually it is not necessary to have a dumpman. However, a laborer or two on the dump to help spread the dumped material is sometimes advisable.

FRESNO SCRAPER PERFORMANCE

Considerable study of fresno work has been made by the engineers of the U. S. Bureau of Public Roads, and the following discussion has been abstracted from reports published in *Public Roads*, the official publication of the Bureau.

It has been found that the greatest loss in fresno output is due to short loading. It takes as long to haul a short load as to move a full one. Poor plowing is often a factor in short loading. Especially on short hauls every effort should be made to secure heavy loading. However, on long hauls it is not advisable to attempt consistent heavy loading because of the extra work thrown on the teams. In a haul of 100 ft. the round-trip time averages 2.2 min. and 27 trips are made in 1 hr. Only $1\frac{1}{2}$ min. of the trip time is spent in hauling to the dump, which means that the team is under full load $13\frac{1}{2}$ min. per hour. On a 300-ft. haul the time required per trip is 4.2 min. and there are 14 loads per hour. In this case the team is under full load $1\frac{1}{2}$ min. per trip or 21 min. per hour. The fact that on the longer haul the stock performs 50 per cent more heavy work during the day than on the short haul explains why stock generally shows a distinct loss of weight if held on long haul work for any length of time. To make a success of a scraper job the stock must be kept in good shape.

Consistency of performance is essential for an economical job. On a normal fresno job, with an average haul of 150 ft., the average output under average management would be about 73 cu. yd. per fresno per 10-hr. day. Under good management it would be about 95 cu. yd. per fresno per day. With a 10-fresno outfit the difference in output would be 220 cu. yd. per day—a considerable amount.

On all scraper jobs it is essential that the foreman be always on the job. Studies made by the Bureau of Public Roads show this. On a job, with no foreman present, the output per fresno on a 100-ft. haul was 20 trips per hour. When the foreman was on the job the output increased to 30 trips per hour.

No significant differences have been found in the rate at which such materials as sand, light gravel, loam, or clay are moved once the load is taken. There is little variation in the pace of the mules either in moving the material or returning from the dump.

The following table gives the output under good and average management for standard 4-cu. ft. fresnos for various lengths of haul.

TABLE I.—OUTPUT FOR 4-FT. FRESNOS FOR VARIOUS HAUL DISTANCES

Haul distance, feet	Loads per fresno per hour	
	Good management	Average management
50	54½	38
75	44	31
100	37½	27
125	32½	24½
150	28½	22
175	25½	20
200	23	19
250	19½	16
300	16½	14
350	14½	13
400	13	11½

The economical limit of haul for fresnos is usually around 300 ft.

Fresno scrapers are often used to spread material brought to dams in cars and dumped from trestles, or material hauled to the embankment in wagons and dumped in piles. At the Kachess dam, in Washington, one fresno, under normal conditions, spread about 115 cu. yd. of clay core material in an 8-hr. shift. When working in gravel, which was more easily loaded than the clay, and when the haul distance was short, one fresno spread from 150 to 175 cu. yd. per 8-hr. shift on the same job.¹

On a canal contract in the west, about 350,000 cu. yd. of earth material was excavated by 15 cu. ft. fresnos and placed in the banks or wasted. The average amount hauled per fresno per 8-hr. day was about 90 cu. yd. On another contract involving over 1,000,000 cu. yd. of excavation in a very light lava ash, the average amount of material moved per fresno per 10-hr. day was 120 cu. yd.

¹ *Eng. News*, Vol. 69, p. 997.

WHEEL SCRAPERS

The ordinary two-wheel scraper (see Figs. 3 and 4) is essentially a large drag scraper carried on wheels and arranged with a mechanism for loading and dumping. A long handle or bar fastened by a yoke to the sides of the scraper is used by the driver to hold down the cutting edge of the scraper when loading. The pan is raised off the ground when the load is being transported.

These scrapers are used on excavating jobs (suitable for scraper operation) where the hauls range from about 200 to 800 ft. Wheel scrapers are often used with drag or fresno scrapers on

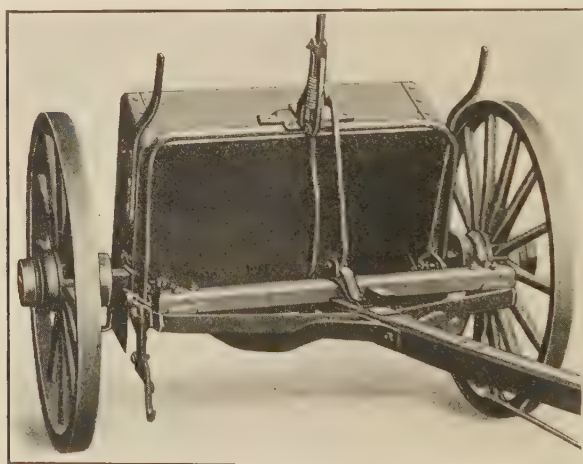


FIG. 3.—Standard wheel scraper.

The scraper pan is in the position shown when the wheeler is returning to the borrow pit for a load. (*Photo from Western Wheeled Scraper Company.*)

jobs where the excavation is extended some distance, as on highway grading or in small ditch construction. The ordinary two-wheel scrapers are made in sizes ranging from 10 to 17 cu. ft., rated capacity. As in the case of drag scrapers, the working capacity will be from 25 to 40 per cent less than the rated capacity. A complete outfit for wheel-scraper operations will consist of the necessary scrapers and teams, one or more snatch teams to be used when loading, a man to load, and a man or two on the dump.

The snatch team is used when loading to help pull the scraper through the material. An extra man lowers the pan, guides it

while loading, and raises it when full. At the dump the dumpman releases the dump handle. The driver takes no part in the loading or dumping of the scraper. Sometimes a shovelman is used to follow the scraper as it is being loaded and fill up the space at the back of the pan.

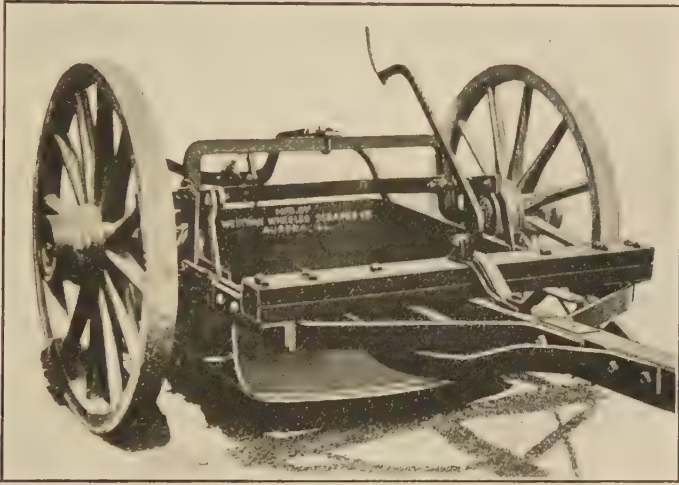


FIG. 4.—A sturdy wheel scraper for rough work.

In this view the scraper pan is in digging position. (*Photo from Western Wheeled Scraper Company.*)

WHEEL-SCRAPER METHODS AND PERFORMANCE

All scraper work consists of three major operations, loading, hauling, and dumping, and all of these operations are interdependent in carrying on a job in an economical manner. The secret of success on a scraper job is to keep the whole outfit moving. If the loader, snatch team, and dumpman are always busy, and all the scrapers are on the move all the time, then the job is being handled properly. Too many scrapers on a job is as bad as not enough.

The nature of the material will have much to do with the progress of wheel-scraper work. Loading is easy in sand or sandy material, and harder in loam or clay, but it usually takes longer to pull a loaded scraper out of sandy material because the wheels will be buried in the sand. Loose sand will not stick in the scraper during transportation as much as loam or clay. Observation of many jobs shows that the principal thing to be guarded

against on wheeler work is incomplete loading. The next important factor is proper spacing, which means having the right number of scrapers on the job so that it will run smoothly, with no congestion at either end and no idle time for the snatch team or dumpman. The proper number of scrapers will vary with the length of haul.

The following discussion of the economical use of wheel scrapers has been abstracted from an article by J. L. Harrison, Highway Engineer, U. S. Bureau of Public Roads.¹

Under present-day conditions the wheel scraper has become a tool to be used largely in connection with some other implement, usually the fresno or drag scraper. This is because there is a limited haul range over which the wheeler is more economical than some other type of earth mover. The question arises, at what point should a shift be made from one type of scraper to the other? On the basis of general theory this change (to wheelers) should be made at a little over 300 ft. Grading contractors commonly make the shift between 300 and 400 ft. But while the proper exchange point as between fresnos and wheelers is generally assumed to be under 350 ft., for outfits of ordinary size if all of the outfit is utilized, a generalization of this sort overlooks two facts of considerable importance.

1. An error of 50 ft. in the selection of the exchange point will often affect the unit cost at which excavation is handled by 10 per cent or more.

2. The size of the outfit together with the pay scale prevailing may affect the exchange point by more than 100 ft. On projects involving a large amount of haul between 275 and 450 ft., therefore, the cost of moving material over these distances may easily be affected as much as 30 per cent or more by error in the selection of the exchange point.

The differences in organization between a wheeler and a fresno outfit are principally that the fresno, drawn by three mules, is loaded, hauled, and dumped by the team and driver; while the wheeler, hauled by two mules, must be helped in loading by a snatch team and loader and at the dump by the dumpman. The fact that the wheeler outfit needs a snatch team, which is not required in the fresno organization, has an important effect on the relative output of the two organizations. In the case of the fresno, output depends directly on the haul distance. When

¹ "Public Roads," December, 1924.

the haul distance is short the output is relatively large, and there is a uniform decrease in output as the haul distance increases. On the other hand, the output of the wheeler organization is limited in the shorter hauls by the capacity of the snatch team to load. With increase of haul distance, however, a point is reached beyond which the output is governed by the time required for haul.

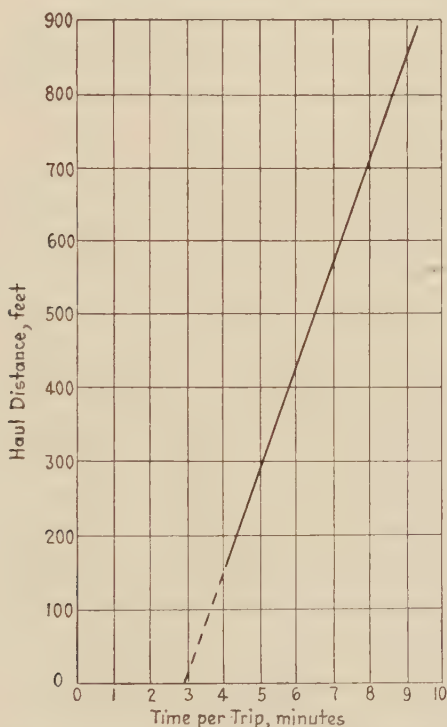


FIG. 5.—Graph showing average time required in moving a load by wheelers over various distances.

Loading time of wheelers averages about 0.75 min., composed of 0.35 min. to load and 0.4 min. for exchange of snatch teams. Knowing this, the number of wheelers that can be loaded with one snatch team without delay can be calculated from the graph (Fig. 5), which gives the average time required in moving a load over ordinary working distances.

For example, suppose the average haul is 400 ft. Then, from Fig. 5, the average time per round trip will be 5.9 min. As the

average time required to load one wheeler is 0.75 min., it follows that eight wheelers ($5.9 \div 0.75$) operated with average efficiency will deliver a wheeler supply to the snatch team which will slightly exceed the capacity of the snatch team as commonly managed.

The following table gives the number of wheelers which can be loaded by one snatch team at various haul distances with average management.

TABLE II.—AVERAGE NUMBER OF WHEELERS LOADED PER SNATCH TEAM

Length of haul, feet	Number of wheelers per snatch team
165 to 270	6
270 to 375	7
375 to 480	8
480 to 585	9
585 to 690	10
690 to 795	11
795 to 900	12
900 to 1,005	13
1,005 to 1,110	14

As long as the snatch team is unable to load all the wheelers which can be made available the wheeler output is practically constant and is fixed by the rate at which the snatch team can work. The output remains constant until the haul distance becomes so long that the full supply of wheelers is thrown in, after which any further increase in haul distance is accompanied by a drop in production. Whenever there is a surplus of wheelers, the snatch team sets an absolute limit on the output. Production cannot be boosted by adding more wheelers after the capacity of the snatch team has been reached.

While it is true that at hauls ranging from 300 to 500 ft. wheeler output is larger than fresno output, it does not always follow that it is cheaper to use the wheeler outfit. It will be necessary to work out an operating cost ratio between the two types of outfit to make sure which is the cheaper. The ratio of the output of fresnoes to the output of wheelers for equal cost per cubic yard on equal haul distances will vary considerably, depending on the wage scale prevailing and the sizes of the outfit.

Losses due to minor delays may be considerable in the aggregate. These losses can be kept down largely by the constant

supervision of the foreman. A wheeler job, like any other scraper job, requires watching and direction. On one job the temporary absence of the foreman caused the output per wheeler to shrink from 8 to 6 cu. yd. per wheeler per hour on a 100-ft. haul, and from 3.7 to 3.2 cu. yd. per wheeler per hour on 500-ft. hauls. The foreman's absence cost the contractor 2 cu. yd. per hour for each wheeler operating on a 100-ft. haul, and $1\frac{1}{2}$ cu. yd. per hour for each one on a 500-ft. haul. There were five wheelers on the job, so the loss was considerable.

Levee Construction.—A wheel-scraper outfit (see Fig. 6) was used on a levee job in southern Ohio. This levee was built



FIG. 6.—Wheel-scraper outfit on levee job.

The topsoil was first removed and saved for covering the finished levee. The underlying material was gravel and clay.

entirely from side borrow, except that it was top soiled with material obtained from the surface of the borrow pit, which was hauled to one side temporarily and then later hauled onto the levee. The material was a clayey loam, with some gravel. The total yardage in this job was 13,945 cu. yd., and the levee was about 9,000 ft. long. The outfit used consisted of seven wheelers, two snatch teams, one plow team, three men loading, and one man on the dump. The average force on the job during the 58 workings days was:

1 $\frac{1}{8}$ foreman	at \$6.60.....	\$ 7.42
1 $\frac{1}{3}$ dumpman	at 4.40.....	5.87
1 plowman	at 3.85.....	3.85
2 $\frac{3}{4}$ loaders	at 3.85.....	10.59
7 teamsters	at 3.30.....	23.10
3 teamsters	at 3.85.....	11.55
1 waterboy	at 2.20.....	2.20
7 $\frac{1}{2}$ wheel teams	at 4.95.....	37.13
1 $\frac{1}{2}$ plow teams	at 4.95.....	7.42
2 $\frac{1}{4}$ snatch teams	at 4.95.....	11.14

Total average daily cost \$120.27

This work cost 50 cts. per cubic yard, exclusive of finishing and of cost of moving to and from the job.

There was some very long haul on this job. It was found that for each 1,000 ft. of haul 9 min. were required for a round trip of a scraper. Loading and dumping each took 1 $\frac{1}{2}$ min., on the average.

Tractor-hauled Scraper Work.—A large pit was opened up by the American Cement Plaster Company, at Acme, Tex., by a wheel-scraper outfit hauled by gasoline tractors. Teams and laborers were very hard to get in the vicinity of this job, and it was decided to try out the tractors. The excavation was 12 ft. deep; all material was hauled to a dump on the surface of the ground away from the pit.

Two 5-ton tractors, each hauling three 16 cu. ft. wheel scrapers, comprised the outfit. Each train was manned by two men, one operating the tractor and one loading and dumping the wheelers. With a maximum haul of 1,200 ft. it was found that the average output was 400 cu. yd. per 10-hr. day. A tractor pulling three scrapers would make four round trips in the same time that three trips were made by a team-drawn scraper on the same length of haul. It was figured that 25 per cent was saved on labor due to the use of the tractors, as the daily output was about what could be expected of a 12-team outfit on similar work. The tractors consumed 25 gal. of gasoline each per 10-hr. day.

On another job, a basement excavation, a tractor-wheeler combination was used. The excavation was 12 ft. deep and 200 ft. across. The maximum haul was 200 ft. The outfit consisted of one No. 21 $\frac{1}{2}$ wheel scraper pulled by a 12-hp. gasoline tractor. It was stated that this outfit handled as much work per day as three team-hauled wheelers on similar work.

CHAPTER III

THE ELEVATING GRADER

An elevating grader is an excavating machine which is equipped with a plow for digging and a transversely traveling belt that elevates the excavated material and dumps it into wagons or trucks alongside the grader or directly onto the ground (see Fig. 7). The entire mechanism is mounted on a four-wheel frame

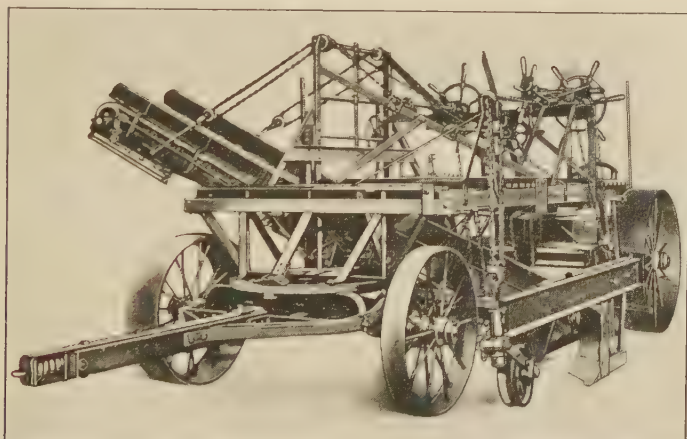


FIG. 7.—An elevating grader with plow of mold-board type.

The plow is at the lower right of the illustration; the elevator extends through the frame, dumping the load to the left. The machine may be drawn by tractor or teams of horses or mules. (*Photo from Western Wheeled Scraper Company.*)

with metal broad-tired wheels. The plow may be either of the disc or moldboard type. The elevator frame (Fig. 8), upon which the belt is mounted, may be adjusted for inclination with the vertical and also may be moved in or out from the main frame of the machine at right angles to the latter. The plow, which is suspended from a beam, may be moved in any direction suitable for proper cutting.

Elevating graders are made in several sizes, though the standard size is most generally used. This size machine has an ele-

vator which will deposit material from 15 to 21 ft. from the plow. A larger machine has a conveyor which will dump material as far as 30 ft. from the plow.

The graders may be drawn by horses or mules or by tractors. When horses or mules are used to draw the machine, from 14 to 20 head will be needed on a standard size machine.

The traveling belt is driven by a bull-wheel attachment which furnishes power to the belt as the machine is pulled along. Some elevating graders are equipped with a gasoline engine to drive the belt; however, this type of machine is not in common use at the present time.

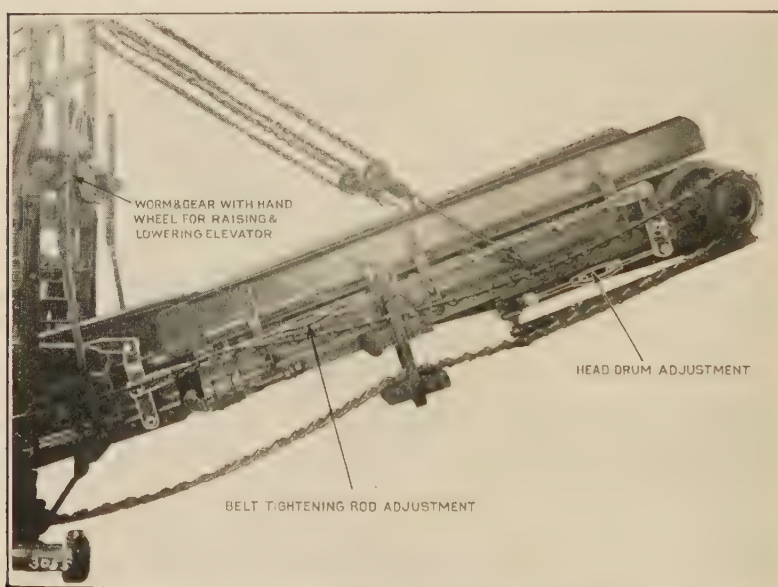


FIG. 8.—Detail of elevator and frame.

The elevator is raised and lowered by an operator on the machine. The moving belt rides a series of rollers fastened in the frame. (Photo from *Western Wheeled Scraper Company*.)

ELEVATING-GRADER OPERATION

Elevating graders are used principally for road grading, striping, small ditching, and excavating for levees, reservoirs or large pits. These machines, under favorable conditions, can load wagons quickly and economically, and there is no doubt that the bottom-dump wagon is a more efficient hauling device than

any type of scraper. The field of the elevating grader is limited, however; it cannot be used in loose, dry sand or sandy material which will not plow, nor in wet or rocky ground; it is not well adapted to work in rough country where the slopes are steep and the changes in slope abrupt. The best materials for elevating-grader work are clay and loam, and most satisfactory results are obtained when the machine can work in level or gently rolling country.

Road Grading.—The following discussion of the use of the elevating grader on road work has been abstracted from a series of articles entitled "The Wagon and the Elevating Grader," by J. L. Harrison, Highway Engineer, U. S. Bureau of Public Roads, which appeared in *Public Roads* for April, May, and June 1925.

On a road-grading job which is to be handled by elevating graders and wagons the problem is made up of three principal factors: (1) the output of the grader, (2) the length of haul, and (3) the wagon supply necessary.

Theoretically a grader should excavate 5,000 cu. yd. per 10-hr. day, if it takes out a cut or bite of 1 sq. ft. cross-section and proceeds at a constant speed of $3\frac{3}{4}$ ft. per second. Actually, on the average road-grading job, from 650 to 1,000 cu. yd. per 10-hr. day constitutes the usual output. The causes of this wide discrepancy between theoretical and actual output are mainly: (1) failure to maintain a full cross section while cutting, (2) failure to maintain full speed while moving, and (3) time losses during the working period.

Full cross-section of cut cannot be maintained constantly except on an ideal job, due to variations in the kind and condition of soil and to differences in elevation of the ground surface. So some loss is bound to occur on this account. It is possible to approximate a constant speed of about $3\frac{3}{4}$ ft. per second, if sufficient power is applied to the machine and enough wagons are used, considering the length of haul.

Under average conditions a $1\frac{1}{2}$ -cu. yd. dump wagon is loaded in about 75 ft. of run of the grader, and the average loading time is about 23 sec. The average time for exchange of wagons is around 18 sec., but by good management this time can be reduced. Turning time averages about 45 sec.; the shorter the cuts the greater is the loss of time due to turns. Another time loss occurs

when resting the stock. If tractors are used to pull the graders, this loss can be eliminated.

The elevating grade works in a loop, taking out a cut along one side of the excavation, then turning, and taking a cut on the other side. Sometimes a cut can be made only along one side, as in side-hill cuts, and the machine returns idle. When working, plenty of room is needed alongside the machine for the wagons, and also for making turns at the ends of the loop.

Fluctuations in the length of haul on a given project tend to high costs; therefore, the nearer the cuts and fills can be balanced



FIG. 9.—A tractor-drawn elevating grader in operation. This view shows a typical road-grading job where the material was suitable for elevating-grader operation.

so as to make the hauls about equal the cheaper the work can be done. Adjustment of the size of the wagon train to the output of the grader which is appropriate for long hauls cannot be appropriate for short hauls, yet practical considerations make it difficult to change the size of the wagon train.

As on scraper work, much of the success of elevating-grader operation depends on the constant supervision of a competent foreman or superintendent.

When the grader is hauled by horses or mules, three men will be needed to operate the machine, one to look after the plowing and loading and the others to handle the stock. If a tractor is used, only two men will be needed (see Figs. 9 and 10).

The average output on highway work will usually not exceed 60 loads per hour.

In Nebraska, much road grading has been done by elevating graders of the standard size and type on major cuts and fills.

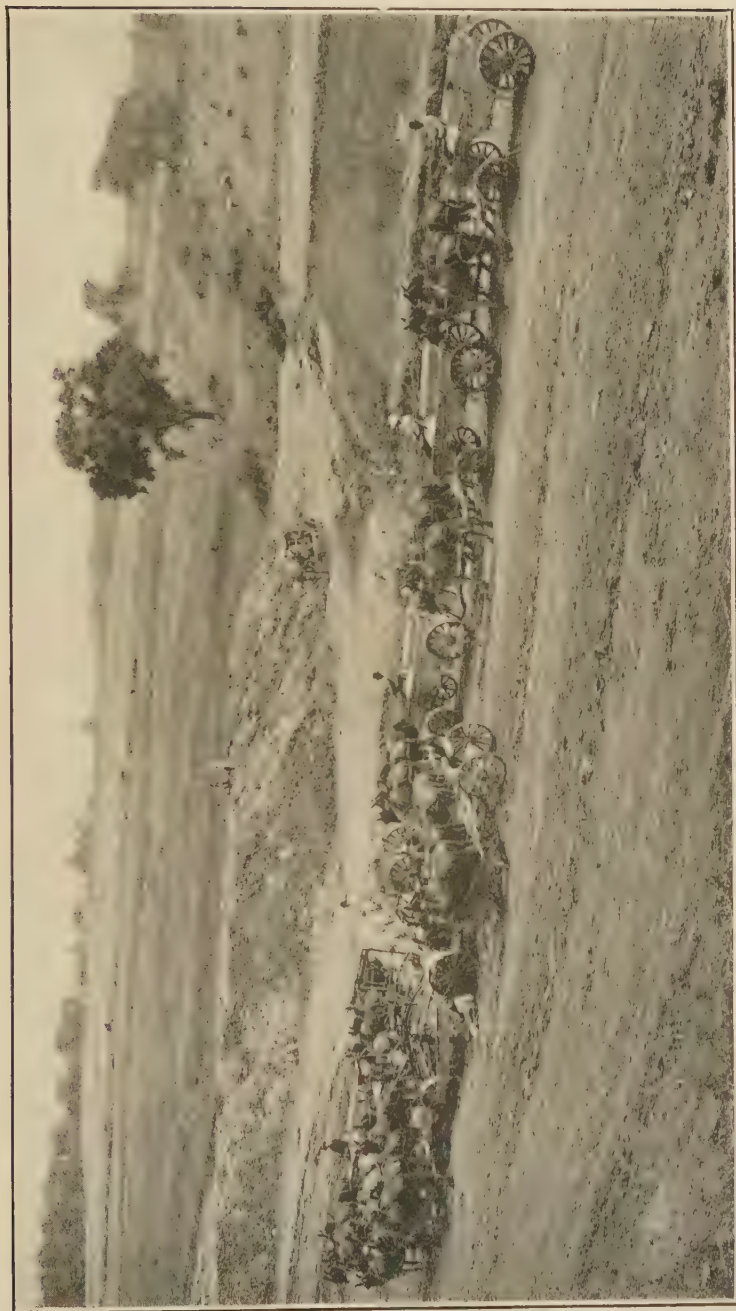


FIG. 10.—An elevating-grader outfit on a railroad grading job. Under favorable conditions, elevating graders and wagons can be used economically for railroad-grading operations, especially when the excavation is from side-borrow pits. In this view the machine has been stopped a moment while adjustments are made to the elevator.

The standard roadbed section is 24 ft. wide, with a 6-in. crown. When the machines were team hauled, it was common practice to use 16 horses, with 3 men on the grader crew, and from 3 to 9 teams hauling dump wagons. On some jobs the machines were hauled by 10-ton gasoline tractors, caterpillar mounted, and this method of handling was considered more economical. The tractors could turn the grader more easily than teams could and no time was lost stopping to rest, so the work proceeded more steadily.¹

Ditching. The elevating grader is most efficient in working out shallow road ditches, but it is used also to excavate some small,

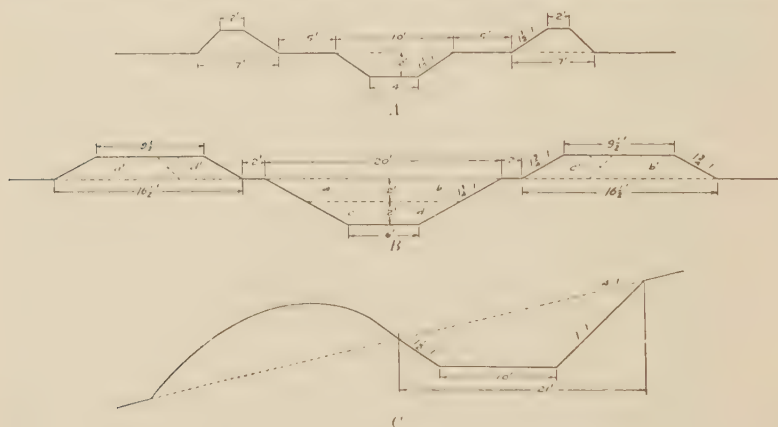


FIG. 11.—Cross-sections of some ditches which may be dug by elevating graders.

(See text for explanation.)

dry drainage ditches. The disc plow is best for this work. Dressing up of the ditch sides and bottom can be done with scrapers or by hand. Several typical cross-sections of ditches which may be handled by elevating graders are shown in Fig. 11. To cut a ditch of the dimensions shown in diagram A, a machine with a 15-ft. elevator is suitable. The excavation is accomplished usually by making two runs of the machine, up one side and down the other, the material being thrown from the left side of the ditch to the right spoil bank, and vice versa. This method of excavating a ditch is called cross-fring.

Diagram B represents a ditch of large cross-section. One method of handling an excavation of this size with an elevating

¹ *Eng. News-Record*, Vol. 86, No. 6.

grader is to take out the first 2 ft. in depth by plowing from outside to centerline and then taking out the bottom 2 ft. of depth by cross-firing. Diagram *C* represents a ditch on a side hill. On such a job the cut can be made in one direction only. A machine with a 21-ft. conveyor would be needed for this work. Sometimes, if the cross-section of the ditch is wider and deeper than can be cut out at one operation, graders of different sizes may be used, one following the other through the cut.

Ordinarily, the elevating grader may be used to best advantage on ditches that are shallow and have wide bottoms, but ditches averaging 3 or 4 ft. in bottom width have been dug economically by the smaller machines. Sometimes an elevating grader is used to take out the top section of a ditch, the rest of the excavation being done by scrapers or by hand.

Open Pits and Borrow-pit Excavation. The methods used to excavate pits for reservoirs or other structures, or borrow pits for embankments are much the same as described above for road grading. The machines proceed up and down the cuts taking out progressive slices of material. It is well, if possible, to haul from both ends of the pit, which saves much turning of the wagons. If the haul is long or the grades out of the pit are steep, three- or four-horse teams should be used on the dump wagons.

Elevating graders drawn by caterpillar tractors were used as the principal equipment for excavating a bowl-shaped depression for a timber and earth stadium at Leland Stanford, Jr. University, Palo Alto, Calif. The excavation was oval shaped in plan, 360 by 540 ft. at the level of the inner field, and averaged 25 ft. in depth, measured from the original ground level. The material was dry clay underlaid with gravelly sand. Three graders handled the major excavation, loading into $1\frac{1}{2}$ -cu. yd. dump wagons, each hauled by four mules. To trim the slopes and work out the corners, four-horse fresno scrapers were employed. The maximum grader output on this job was 3,696 cu. yd. in a 10-hr. day, and the average output for the three machines throughout the job was from 17,000 to 20,000 cu. yd. per week of six 10-hr. days. The haul was short, as all material was deposited in an embankment surrounding the field.¹

In connection with the construction of the Lower Deer Flat embankment, built by contract for the U. S. Reclamation Service in Idaho, 586,300 cu. yd. of earth was excavated by elevat-

¹ *Eng. News-Record*, Vol. 88, No. 18.

ing graders. The material was transported to the dam in wagons, the average haul being 400 to 500 ft. Two elevating graders were in constant use, the output per grader being from 575 to 725 cu. yd. per 8-hr. day under favorable conditions. When the borrow pits were moist and firm each grader was hauled by a 22-hp. steam traction engine, but when the pits became dry and loose the traction engines could not do the work and were replaced by teams of 16 to 18 horses. The net cost of hauling the graders by teams (not including general items such as depreciation, repairs, interest, etc.) was over two and one-half times as much as by traction engine, but it should be noted that at the times when teams were used the traction engines could not do the work at all. The traction engines were not equipped with caterpillar treads, however; it is probable that had they been so equipped they might have handled the work under all conditions.

Near Coleman, Tex., an earth dam 1,100 ft. long and 55 ft. high, with a corewall of puddled clay, was constructed. Rolled-fill construction was used for the main embankment. An elevating grader was used successfully to handle the placement of the clay core material. The clay was excavated by a steam shovel and loaded into $1\frac{1}{2}$ -cu. yd. dump wagons which deposited the material parallel to the core trench throughout the length of the dam. Then a tractor-drawn elevating grader plowed through the material and cast it from the conveyor belt directly into the core trench.¹

¹ Successful Methods. August, 1923.

CHAPTER IV

THE POWER SHOVEL

No machine for excavating is more widely used than the power shovel and it is only within the last few years that any other type of excavator has been considered equal to it for dry land work in earth or rock. While recent developments of dragline and cable-way excavators have made these machines adaptable to many jobs of excavating, they have not supplanted the power shovel for certain classes of work. For digging from the bank and loading upon transporting equipment within easy reach, in the dry, and protected from possible flooding; for making excavations for building foundations and other structures situated in close quarters; for large stripping operations and quarrying; and for many minor excavating jobs the shovel is still the favored type of equipment. It is probable that the dragline excavator will never supplant the shovel for certain kinds of work, though recent experience has proved the dragline adapted to many jobs that had previously been handled only by shovels. The advantages of the dragline are set forth in Chap. V.

DEVELOPMENT OF THE MODERN SHOVEL

Some interesting data on the early development of the steam shovel is presented in *The Excavating Engineer* for September, 1926. It is stated that the first successful mechanical shovel, steam operated, was designed by William S. Otis, and built in 1837 (see Fig. 12). This machine was used on a section of the Baltimore and Ohio Railroad in Maryland, and was later used on the first Welland Canal in Canada. It was of the boom-and-mast type and operated on a track of heavy timbers of 7-ft. 10-in. gage. One engine furnished all the power. There were three motions to the shovel—hoisting, crowding or digging, and swinging. The boom or crane was a triangular-shaped structure supported at both bottom and top of the mast, and at the top of the mast was the swing circle. Chains operated the hoist and swing mechanism. A vertical boiler was located at the rear

of the truck. Other machines of the same type were built later by John Souther, of Boston. For some years there was no essential change in the design of these machines.

The next development was the introduction of three engines, one for each motion. All of the machinery was mounted on a car body, provided with trucks, which remained at right angles to the face against which the machine was working. The boom, dipper, and dipper sticks, with their swing circle, were the only swinging parts of the machine.

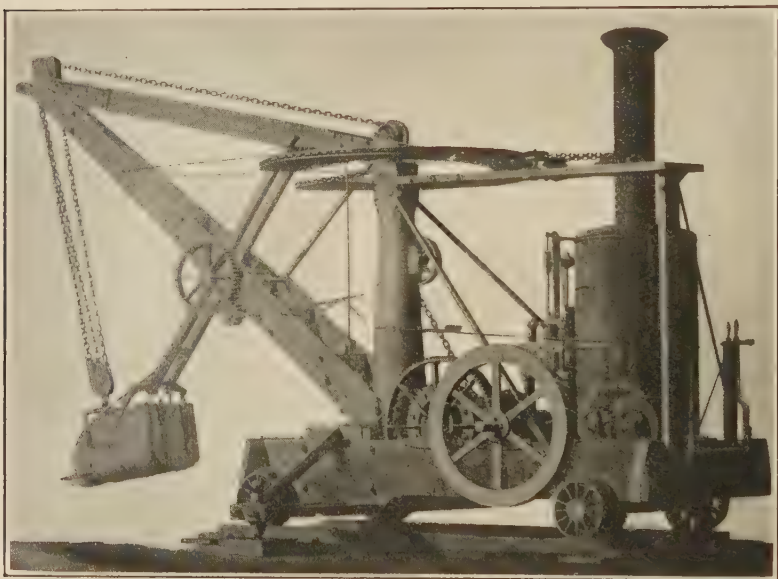


FIG. 12.—The Otis steam shovel.

This shovel, built in 1837, was probably the first successful mechanical shovel.
(From the *Excavating Engineer*, September, 1926.)

The mast-type shovel was later supplanted by the A-frame type, having a boom with a bearing at the lower end, where was located the swing circle. Guy rods ran from the point of the boom to the top of the A-frame. This machine was developed into the modern boom-swinging type known as the railroad-type shovel (Fig. 13).

The final development of the steam shovel is the full revolving type, now made in all sizes and adapted for many kinds of digging.

Among the advantages of the revolving-type over the boom-swinging type shovel are the following:

1. It can dig ahead all the time, never having to "deadhead" back to start a new cut.
2. It can dig and load at any point in the circle of its swing.
3. It can be more compactly built, permitting its use in close quarters.
4. It can be converted into dragline, trenching machine, or crane by the use of a few attachments.



FIG. 13.—A powerful railroad-type shovel in a heavy earth cut. This type of machine is especially adapted to rock excavation and other heavy work.

DESCRIPTION OF SHOVELS

The fundamental principles of all power shovels are about the same, each involving three motions. The first is the advancing or the crowding motion which brings the dipper into contact with the material to be excavated. The second motion loads the dipper by hoisting it through the material. Both of those motions are in the vertical plane, as their ultimate object is to lift. After the material has been excavated by crowding and hoisting, the dipper must be swung around horizontally to unload. It is in the application of power to these three necessary motions that shovels differ. At the present time both the boom-swinging

and full-revolving types are being built, though the tendency is toward the revolving type.

Boom-swinging or Railroad-type Shovels.—These shovels, originally devised for railroad work, are used for many other pur-



FIG. 14.—Boom and dipper on 70-ton railroad-type shovel.

A 3-cu. yd. dipper is being used on this machine, which is working in a shale and clay formation.

poses, such as stripping and quarrying, and tunnel work. The entire mechanism is mounted on a two-truck car body to operate on standard-gage railroad track. Some of the newer models can be had on traction wheels or crawler traction. The boom and dipper are at one end of the body, the engines and boiler or

other propelling mechanism at the other. On either side, at the forward end, are two jackarms or struts, having a spread of 15 to 20 ft., according to the size of the shovel. These jackarms help to balance the shovel and prevent it from overturning when the boom is swung far around to the side. At the base of the boom is the swing circle, which is in effect a large sheave about which pass the cables which swing the boom. The total arc of swing for the boom is from 180 to 200 deg. The boom is usually fixed at an angle of 45 deg. above the horizontal. The upper end of the boom is supported by two bars which run back to the collar on the A-frame. Between these bars passes the dipper handle, which is moved up and down by a rack and pinion, the latter operated by the boom or crowding engine. The swinging mechanism and the crowding mechanism are operated by separate engines or motors. Chain or gear drive to the trucks moves the machine forward or backward. Shovels of this type may be had in a variety of sizes, ranging from $\frac{3}{4}$ - to 6-yd. dipper capacity (see Fig. 14). The largest machine has a rated capacity of from 250 to 500 cu. yd. per hour. The maximum depth of thorough cut which can be made by this type of shovel ranges from about 12 to 18 ft., and the clear lift, loading into dump cars, will be from 14 to 16 ft. These shovels can dig from 4 to $6\frac{1}{2}$ ft. below the track on which they stand.

Revolving Shovels.—Full-revolving shovels are made in all sizes, ranging from the small $\frac{1}{2}$ -yd. machine used on light work or in close quarters to the huge 8-yd. dipper shovels used chiefly in stripping operations in the mining districts. The essential difference between the full-revolving shovel and the boom-swinging type is, of course, in the swinging mechanism. This consists of a revolving frame, which provides a base for the engines or motors, all the main machinery, and the boom. The frame rotates on several large rollers which travel on top of the swing gear; the frame may be rotated in either direction in a full circle, the boom swinging with the frame. The machine is so designed and balanced that jackarms are not needed.

Small revolving shovels (Fig. 15) usually have a clear height of lift for digging and loading of from 11 to 18 ft. This means that the shovel can be from 6 to 13 ft. below the ground surface and load wagons or cars on the surface. Some of the newer shovels have extra long booms for handling higher lifts. The large revolving shovels (Fig. 16) can handle cuts of from 30 to 85 ft. in vertical

height and can load cars or trucks from a depth of 20 to 70 ft. below the top of the cars or trucks.



FIG. 15.—Small revolving steam shovel.

Caterpillar mounting was furnished for this machine which has a $\frac{3}{4}$ -cu. yd. dipper. (See Fig. 20 for machine with traction-wheel mounting.)



FIG. 16.—A large revolving steam shovel.

This machine is equipped with a 8-cu. yd. dipper. It is mounted on standard-gage trucks. (Photo from Bucyrus Company, South Milwaukee, Wis.)

Mountings.—Practically all boom-swinging shovels are mounted on two trucks of four wheels each, made to operate on standard-

gage railroad track. Some of the larger revolving shovels are also mounted in this manner. Some of the newer boom-swinging shovels are now mounted on crawler traction. The small- and medium-size revolving shovels are mounted on wide, flat-tread wheels, called traction wheels, or on caterpillar or crawling traction. When traction-wheel mounting is used, the machine is propelled by power from the main engine or motor applied to one axle, while the other axle is constructed so as to provide motion in either a vertical or horizontal plane, so that the machine may be steered and may follow the contour of the ground. Machines mounted on traction wheels usually must travel on timber mats where the ground is very rough or soft. Caterpillar traction is common for all but the largest shovels, as machines so mounted have much greater flexibility and can move about without the mats.

Power.—Originally the power shovel was of necessity a steam machine, but recent improvements and developments of the internal-combustion engine and the electric motor have made it possible to use either or both of these for operating shovels. Nearly all boom-swinging type shovels use steam power. The large revolving stripping shovels are equipped for either steam or electric drive. The smaller, revolving machines use steam, electric, or gasoline power, or a combination of gasoline and electric drive. One manufacturer uses direct-connected air-compressor engines for the crowding and swinging operations, a gasoline engine supplying the primary power. Diesel oil engines are used on some of the larger machines.

Selection of power equipment for a given job depends largely on local conditions and availability of supplies. Nearly all the smaller shovels for general use are either steam or gasoline driven. On large projects where electricity is available, the electric machines offer some advantages over the steam-powered type.

Crew.—The operating crew for a small revolving steam shovel usually consists of a runner or operator, sometimes a fireman, and from one to three ground men to assist in the various labor jobs around the machine. Sometimes the operator does the firing. On larger steam machines a fireman is always necessary, and on the boom-swinging type it is customary to have a cranesman as well as a dipper operator. The cranesman operates the boom or crowding engine. On large jobs more pitmen will be needed than on small ones. The small electric machines can be oper-

ated by one man, if caterpillar mounted or working on smooth ground where mats are not necessary. The same is true of the small gasoline machines. Where an electric machine is used it is well to have an electrician available.

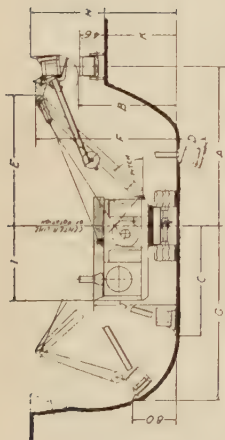
Delays.—The greatest cause of delay in shovel work is in the removal of the excavated material. Any shovel can equal or exceed its rated capacity if provision can be made to get the excavated material away from it rapidly enough. But conditions seldom favor such rapid removal. Too great care cannot be given to securing proper and ample equipment of locomotives and cars, or trucks or wagons, and in the proper systematizing of the transporting and dumping service. The economic success of shovel work depends very largely on having an empty car or truck always ready to replace a loaded one under the dipper.

Second in importance in the cause of delays are breakdowns. Breakdowns cannot be entirely avoided, but they can be minimized by careful attention to the working parts of the machine and by the employment of an experienced and capable operator. A supply of minor repair parts should always be kept on hand, and on large jobs a good mechanic should be employed for the purposes of inspection and repairs.

Shovels of the boom-swinging or railroad type, loading cars, will only be actually digging from 50 to 65 per cent of the working time on the average job. The rest of the time will be consumed in shifting track, moving ahead, waiting for cars, and dead-heading back for new cuts. From studies made of the standard 70-ton steam shovel of the railroad type equipped with 2½-yd. dipper, it appears that the average output per 10-hr. shift should be about 1,500 cu. yd., working in earth or gravel.

Selection of Shovel.—The selection of a power shovel is determined by a great many factors, and no attempt will be made to give more than a few general suggestions.

For miscellaneous small contracting jobs, such as cellar excavations, grading for streets and alleys, subdivision work, etc., the ½- to 1-yd. revolving shovel, caterpillar mounted, is probably the most satisfactory machine. If it is likely that it will be used where electric power is not always available, the steam, gasoline or gasoline-electric machine will be best. To give an idea of the working range of the small machines the following list shows the principal dimensions of one make of shovels:



Steam	Shovels					
	20-B		30-B		50-B	
	Standard	High lift	Extra high lift	Standard	High lift	Extra high lift
Length of boom.....	18'0"	20'6"	23'6"	21'0"	26'0"	33'0"
Length of handle.....	12'6"	15'0"	17'0"	14'0"	17'0"	21'6"
Size of dipper, level full, cubic yards.....	$6\frac{3}{4} \times 6"$	$6\frac{3}{4} \times 6"$	$6\frac{3}{4} \times 6"$	$6\frac{1}{2} \times 7"$	$8\frac{1}{2} \times 9"$	$1\frac{1}{2} \times 9"$
Size of engines { Main.....	$4\frac{1}{2} \times 5"$	$4\frac{1}{2} \times 5"$	$4\frac{1}{2} \times 5"$	$5\frac{1}{2} \times 5"$	$6\frac{1}{2} \times 6"$	$6\frac{1}{2} \times 6"$
Size of engines { Swing and thrust.....						
Diesel and gasoline	Shovels					
	20-B		30-B		50-B	
	Standard	High lift	Extra high lift	Standard	High lift	Extra high lift
Length of boom.....	23'0"	26'0"	28'0"	25'9"	32'6"	38'0"
Length of handle.....	12'6"	15'0"	17'0"	14'0"	17'0"	21'6"
Size of dipper, level full, cubic yards.....	$6\frac{3}{4} \times 6"$	$6\frac{3}{4} \times 6"$	$6\frac{3}{4} \times 6"$	$6\frac{1}{2} \times 7"$	$8\frac{1}{2} \times 9"$	$1\frac{1}{2} \times 9"$
Size of engines: Diesel.....	$3\frac{3}{4} \times 10"$	$3\frac{3}{4} \times 10"$	$3\frac{3}{4} \times 10"$	$3\frac{3}{4} \times 10"$	$4\frac{1}{2} \times 12"$	$4\frac{1}{2} \times 12"$
Gasoline.....	$6\frac{1}{4} \times 8"$	$6\frac{1}{4} \times 8"$	$6\frac{1}{4} \times 8"$	$7\frac{1}{2} \times 10"$	$9\frac{1}{2} \times 12"$	$9\frac{1}{2} \times 12"$

On large-scale operations in the mining industry, in gravel pits and clay plants, and on some other heavy work, the large revolving shovel should be used, provided it is decided that shovels are the preferred equipment. These machines are rapidly replacing the boom-swinging type for heavy work in ore and rock. Until recently no machine except the boom-swinging type was rugged enough to handle such digging, but the new models in large-size revolving machines are being made especially for extra heavy digging. They are operated with either steam or electric power, the choice for a given job depends on the availability of coal or electricity, and the price at which either can be had.

Where large capacity in heavy materials is required, and where standard railroad equipment is available, no machine can beat the boom-swinging or railroad type. However, it should be remembered that these machines have a limited digging range, and on deep cuts much benching will be necessary.

For railroad grading operations the following recommendations are from the report of the Committee on Roadway of the American Railway Engineering Association.

In general, the commonest sizes of shovels for medium heavy work are the 60- to 80-ton machines. For light grading, up to 25,000 cu. yd. per mile, where a shovel can be used economically, a light revolving shovel is to be desired. For quantities of from 25,000 to 40,000 cu. yd. per mile, a shovel of 50-tons is a good size. For quantities of from 40,000 to 60,000 cu. yd. per mile, a shovel of 60 to 80 tons is well suited. For anything over 60,000 cu. yd. per mile the shovel may run up to well over 100 tons economically, if its transportation is not too expensive, and if the ground is fit to carry the weight on the subgrade during excavation.

As the plant charge is an important item, especially on long haul, continuous operation is desirable. Either three 8-hr. or two 10-hr. shifts are recommended.

SHOVEL METHODS AND PERFORMANCE RECORDS

Dry-channel Excavation.—In order to increase the capacity of the Miami River channel at Troy, Ohio, the high-water channel was widened on the north side by removing about 140,000 cu. yd. of material between the old north levee and a new levee embankment. The material was a loamy silt or sand with no rock, and the work could all be done in the dry. All of the exca-

vated material was hauled by trucks or wagons to the new levee embankment. The haul averaged about 500 ft., and the height of fill above the ground averaged 12 ft. Some 81,000 cu. yd. of this material was moved by two steam shovels, each equipped with $\frac{3}{4}$ -yd. dippers, and mounted on traction wheels (see Fig. 17). Seven 7-ton trucks were used for hauling. The digging was easy, but hauling was rather difficult on account of the soft ground. Considerable trouble was encountered when the ground was wet, due to lack of traction for the trucks. The shovels began their cuts at the riverside of the job and worked upstream and down-



FIG. 17.—Steam shovel and truck outfit for earth excavation.

On this levee job a $\frac{7}{8}$ -cu. yd. revolving shovel loaded 7-ton trucks. The material was loam and sand and the average truck load was about $2\frac{1}{2}$ -cu. yd. The loaded trucks climbed an 8 per cent grade in hauling out of the borrow pit.

stream progressively in successive cuts. The loaded trucks climbed an 8 per cent grade in hauling to the fill. A large amount of the work was done during the winter months; however, the weather was mild and the ground was not frozen. This made digging easier, but hauling was more difficult, therefore the shovels were not working at capacity. The average quantity moved per month by the two shovels was 9,000 cu. yd., and the best months' run was 15,900 cu. yd. The shovels averaged 430 cu. yd. each per 10-hr. day actually working; and the trucks hauled an average yardage of 128.4 cu. yd. each per working day of 10 hrs. The contract price for this work was 65 cts. per cubic yard.

Due to difficulty in handling the large trucks on this job, teams and wagons were substituted later. One of the shovels loading into seven wagons, each hauled by three mules, moved a total of 47,000 cu. yd. to complete the job. This outfit averaged 380 cu. yd. per working day. The wagon loads averaged 1.29 cu. yd. each, and an average of 43 loads per team per day were hauled.

This job could probably have been handled cheaper had small cars on narrow-gage track been used for hauling instead of the trucks and wagons, but such equipment was not readily available. The performance on this job emphasized the fact that unavoidable conditions can cut down the rated output of excavating equipment very considerably, a fact that must not be lost sight of in figuring on this class of work.

Rock Excavation.—Excavation for the foundation of the Arrow-rock dam, in Idaho, was a particularly difficult job, due to the location and the nature of the material. Part of it was handled by a dragline machine and part by a 70-ton railroad-type steam shovel, equipped with a 2-yd. dipper. The material consisted largely of boulders of all sizes, some up to about 150 cu. yd. In places they were nested together and the spaces between them solidly packed with finer material. Due to the fact that the work was in a narrow canyon, and the river was subject to frequent rises, it was necessary to build diversion works for the flood flow and to build the dam in sections. Therefore the excavation could not be completed in a continuous operation. The material handled by the steam-shovel outfit was all wasted, as it was not suitable for concrete. It was wasted along the river bank both upstream and downstream from the dam site. Of 58,000 cu. yd. handled by the shovel, over 27,000 cu. yd. was classified as rock. The excavated material was hauled away by train outfits consisting of three 16-ton steam dinkey locomotives and 25 4-yd. dump cars. The cost of moving this 58,000 cu. yd., exclusive of blasting, was 50.3 cts. per cu. yd., of which 24.6 cts. was for digging and loading, 23.8 cts. for hauling, and 1.9 cts. for preparatory expense, which included the cost of assembling equipment. Coal cost \$7.40 per ton. Steam shovel engineers were paid \$150 per month; cranesmen, \$110 per month; laborers, \$2.40 per day; drill runners, \$3 to \$3.50 per day; firemen, \$3 per day; blacksmiths, \$3.50 to \$4 per day; mechanics, \$3.50 to \$4 per day. Work was done in 8-hr. shifts. The total time consumed in

moving the material was about $7\frac{1}{3}$ months, making an average output of 7,940 cu. yd. per month.

The same shovel outfit was used for all of the excavation for the spillway of Arrowrock dam. This spillway is a weir, 400 ft. long, extending back upstream from the north abutment, and a discharge trench about 900 ft. long. Both weir and trench were cut out of a steep side-hill rock slope, standing at approximately $1\frac{1}{2}$ to 1. The side slopes of the excavation varied from $\frac{1}{2}$ to 1 to nearly 1 to 1. Along the uphill side of the excavation the depth of cut varied from about 80 to nearly 250 ft. The material was granite with a light overburden of disintegrated rock. Before the shovel outfit could be installed a bench was opened up by hand and by teams along the line of subgrade for the spillway weir.

The entire outfit was lifted to this bench, a vertical distance of about 250 ft., by a cableway which was already set up on the job.

The bench was first widened into the hillside, and the material above that elevation and outside of the upper cut stakes was moved first. The material was wasted along the side hill upstream beyond the end of the weir, and, at the other end, up a canyon. The trench was then excavated to grade. Two trains, each made up of from six to eleven 4-yd. dump cars, served the shovel. Over 227,000 cu. yd. of material was handled in this excavation, which took 14 months' continuous work. The cost was 57 cts. per cubic yard, divided as follows:

	Per Cubic Yard
Hand labor on slopes.....	0.01
Drilling and blasting.....	0.22
Excavating and loading.....	0.14
Hauling and dumping.....	0.15
Preparatory expense.....	0.05
Total.....	\$0.57

The unit cost of labor and material was as noted above. About 8 per cent should be added to the above cost for administrative, clerical, and general expense.

The shovel crew consisted of a runner, a cranesman, a fireman, and four pitmen; the train crew was two locomotive runners, two brakemen, and about four trackmen.

The average output was 16,742 cu. yd. per month.

In connection with the relocation of the lines of the Big Four and Erie railroads near Dayton, Ohio, a large side-hill cut, mostly in rock, had to be made. On the high side the cut reached a maximum depth of 120 ft., and its total length was 4,500 ft. The total excavation was 657,000 cu. yd., of which 593,000 cu. yd. was rock. This rock was of three formations; the upper, of fairly solid limestone, was about 35 ft. thick; below this was a layer of softer limestone, and the lower formation was of limestone layers interstratified with shale. All the rock required



FIG. 18.—A 70-ton steam shovel loading rock which has been shot.

The rock was blasted in a long windrow ahead of the shovel, the latter then following and loaded the shattered material into cars.

drilling and blasting, mostly done in 8- or 16-ft. lifts, the latter height being used when the steam shovel stood on a level with the cars it was loading, the former when the cars were on the bench above the shovel. Forty per cent dynamite was used, in charges of 100 to 250 lb., the holes being mostly sprung for the charge. Holes were spaced about 7 ft. for the 8-ft. lifts, and about 13 ft. for the 16-ft. lifts. The bottom 28 to 30 ft. of the rock was shot in one lift, 2,500 ft. in length. Five steam drills and four well drills were used, with two jack-hammer drills for lighter work. The well drills made 40 to 50 ft. in a 10-hr. shift; the rock drills

from 60 to 65 ft., the holes being $3\frac{1}{4}$ to $3\frac{1}{2}$ in. in size. The object of the blasting was to just lift the material and leave it in a loose windrow which the shovel could handle readily (see Fig. 18).

The shovel on this job was a steam machine with $2\frac{1}{2}$ -yd. dipper, and 29-ft. boom. It was of the boom-swinging type, mounted on standard-gage car trucks (see Fig. 19). The material was transported in standard-gage 12-yd. dump cars hauled by steam locomotives to the embankments at either end of the cut.



FIG. 19.—Railroad-type steam shovel in rock cut.

This machine was equipped with a $2\frac{1}{2}$ -cu. yd. dipper and a 29-ft. boom, and was mounted on standard-gage trucks.

This outfit averaged about 1,000 cu. yd. per 10-hr. shift. It worked two shifts a day, the monthly output averaging 34,000 cu. yd.

This work was done by contract, the unit price for excavation being \$1.25.

The construction of the Dix River dam in Kentucky involved dumping nearly two million cubic yards of blasted rock into a gorge between two cliffs about 1,000 ft. apart and over 300 ft. high. The construction consisted mainly of blasting, loading, hauling, and dumping the rock. The upstream face of the dam was covered with derrick-laid large stone masonry covered by

a reinforced-concrete apron. The first job was to clear the rock foundation and get in the cut-off wall. The material to be removed consisted of earth, loose rock, and clay. The earth excavation, consisting of 95,700 cu. yd. of material, was handled by two 78-ton standard-gage railroad steam shovels with $3\frac{1}{2}$ -yd. dippers loading into 16-yd. air-dump cars, aided by two revolving steam shovels with $\frac{3}{4}$ -yd. buckets loading into 4-yd., 36-in. gage dump cars. On the other side of the river two revolving $\frac{3}{4}$ -yd. dipper shovels and one $1\frac{1}{2}$ -yd. dipper machine removed 90,500 cu. yd. of loose rock material, loading into 4-yd., 36-in. gage



FIG. 20.—Small revolving steam shovel in channel cut.

Excavation of this earth channel was handled by a $\frac{3}{4}$ -yd. revolving shovel mounted on traction wheels. This is a very light machine.

dump cars. All the material was hauled outside the dam area and dumped. The cut-off trench was drilled and shot, the material loaded into skips and removed by derricks.

Originally it was intended to carry up the main fill in 60-ft. lifts, and a switchback system from the spillway (the source of rock fill) was laid out, using 2 per cent maximum grades, with 1,500 ft. of track between switch points. It developed that this procedure would close the river before the completion of the diversion channel, so the filling was carried across on the 120-ft. level. This was done by dumping from a semicircular track laid on the dump and shifted as the fill was built out. At the higher levels the width of the fill would not permit a circular dump so a narrow fill was carried across on light 60-ft. timber

trestles. Then the dam was widened to the theoretical slope lines by side dumping and shifting track.

The spillway cut furnished most of the rock for the dam. The width of the cut was 250 ft. at the bottom with $\frac{1}{4}$ to 1 side slopes. The deepest cut was 107 ft., and the length of the cut was 2,300 ft. The rock was shot with dynamite and black powder in 6-in. holes, spaced 12 to 15 ft. and 20 ft. back from the face. Three 78-ton railroad-type steam shovels, each with $3\frac{1}{2}$ -yd. dipper, loaded the rock on 16-yd. air dump cars. Eight 48-ton standard-gage locomotives hauled five-car trains to the dam. Two of the shovels were caterpillar mounted and the other was truck mounted.

Two large blasts opened a second rock supply on the other side of the river. One shot, using 82,000 lb. of railroad powder, brought down 88,300 cu. yd. of rock. The second shot, composed of 30 well-drilled holes from 100 to 125 ft. deep, brought down 70,900 cu. yd. All of this material was excavated and loaded onto cars by two $1\frac{1}{2}$ -yd. revolving steam shovels.

All work was carried on in two 10-hr. shifts per day. It is reported that the 78-ton railroad shovels averaged an output of about 1,000 cu. yd. per shift each.¹

Excavation for Large Embankments.—Steam shovels were used for excavating the materials for two large embankments for the U. S. Reclamation Service.

One embankment was 3,000 ft. long and had a maximum height of 70 ft. Material was obtained from five borrow pits, three of which were near the east end of the dam and two near the west end. The average haul was from 1,800 to 2,000 ft. The material was sand, gravel, clay, and some hard cemented gravel which required shooting.

Two 70-ton railroad-type steam shovels, each equipped with $2\frac{1}{2}$ -yd. dippers, were used for the excavation. Materials were hauled by trains, each made up of twelve 4-yd. side-dump cars hauled by 16-ton dinkey locomotives. At the lower elevations, the tracks from each shovel extended the whole length of the fill, but the top 20 ft. of the fill was built with the tracks from each side extending only to the center of the embankment.

The total material excavated was 932,200 cu. yd. The total number of 8-hr. shifts worked by the shovels was 1,021, and the average output per shift was 913 cu. yd. In this computation

¹ *Eng. News-Record*, Vol. 94, No. 14.

the time used in moving shovels back in the pit and the time used in repair work is counted as working shifts and included in the 1,021 shifts. The largest daily output for any month for one shovel was 1,310 cu. yd. per shift for 25 days; the smallest was 678 cu. yd. per shift for 32 shifts.

Excavation for the Beaver Kill dikes of the Ashokan reservoir, constructed for the Board of Water Supply of the City of New York, was handled by steam shovels. A 70-ton railroad shovel operating in sandy clay and served by two trains of 10 to 12 cars (3-yd.) each, with an average haul of 1,800 ft., had an average



FIG. 21.—A revolving diesel-engine shovel mounted on caterpillar traction.
(Photo from Bucyrus Company.)

daily output of 875 cu. yd. (8-hr. day). The total quantity moved was 30,000 cu. yd. The same shovel, digging in boulder clay, and served by three trains of sixteen 3-yd. cars, with an average haul of 4,800 ft., averaged 1,030 cu. yd. per 8-hr. day on a total excavation of 45,000 cu. yd. The shovel crew consisted of an operator, a cranesman, a fireman, and six pitmen.

On another dam built by the U. S. Reclamation Service (Cold Spring dam, Umatilla project), a 70-ton steam shovel of the railroad type equipped with a $2\frac{1}{2}$ -yd. dipper handled the excavation. The material was earth, sand, and gravel, which was taken from a borrow pit near the dam site. The hauling was

done in 4-yd. dump cars hauled by steam dinkeys on narrow-gage track. The length of haul averaged 2.3 miles, with one switch-back. The gravel bank was from 30 to 40 ft. high above the shovel. Four trains of 10 cars each served the shovel, yet the shovel often had to wait for cars.

The shovel output reached a maximum of 2,300 cu. yd. per 8-hr. shift, and averaged 1,600 cu. yd. per shift throughout the job. The total quantity moved was 590,000 cu. yd.

The excavation cost was 3.5 cts. per cu. yd., and the hauling cost amounted to 7.2 cts. per cu. yd., of which 5.5 cts. was for actual hauling and 1.7 cts. for track maintenance. These are operating costs only. While this work was being done wages were: laborers, \$1.60 to \$2.40 per day; shovelman, \$6.20 per day; cranesman, \$4 per day; dinkeyman, \$3.60 per day. Coal cost \$8.60 per ton on the job.¹

Excavation for a large railroad fill was handled by a 70-ton railroad-type steam shovel with 2½-yd. dipper. This was on the Chesapeake and Ohio Northern Railroad in Kentucky. The fill, which totalled 450,000 cu. yd., is 52 ft. high. It was built entirely of earth excavated from a borrow pit, and the average haul was 1½ miles. A filling trestle 23 ft. high was built; after the fill reached the top of the trestle, the track was jacked up as filling progressed. The material was transported in two 6-car trains of 12-cu. yd. dump cars hauled by 60-ton standard-gage locomotives.

The average output on this job was 43,000 cu. yd. per month, and the biggest month's output was 53,000 cu. yd. The shovel worked one 11-hr. shift per day and 6 days per week.²

The U. S. Reclamation Service built in Oregon a gravel-fill dam called the McKay dam. This embankment is faced on the upstream side with reinforced concrete; the structure is 3,000 ft. long and has a maximum height of 160 ft. It contains 2,400,000 cu. yd. of gravel. All of this material was excavated from borrow pits in the valley about 1 mile above the dam. The material was very compact, digging almost like rock. Cuts in the pits averaged 7 ft. in depth, and some water accumulated in the pits to depths of from 6 in. to 2 ft. The excavation was handled by two large electric revolving shovels with 2½-yd. dippers, and equipped with special short booms and dipper

¹ *Eng. Contr.*, May 24, 1911.

² *Eng. News*, Vol. 75, No. 1.

handles. Hauling was done in 4-yd. cars equipped with sideboards, so that each car held about $4\frac{1}{2}$ cu. yd. Trains of 12 cars, hauled by 18- and 20-ton gasoline dinkey locomotives, were used. The average time consumed for a round trip of these trains from borrow pit to dam and back was 40 min. Operating on 8-hr. shifts the shovels averaged 1,200 cu. yd. each per shift.¹

Grading for Road and Street Improvements.—On a job in the middle west a small revolving steam shovel was used for grading 4 miles of new road, involving a total excavation of 72,000 cu. yd. of earth and shale. The shovel was equipped with a 1-yd. dipper and loaded into dump wagons. In thorough cuts the average output was 375 cu. yd. per day, and in side cuts, where the shovel only revolved 90 deg., the average output was 510 cu. yd. per day of 8 hr. The shovel crew consisted of an operator, fireman, and two pitmen.²

On another job in Oregon, which was all side-hill work, a revolving steam shovel with $\frac{3}{4}$ -yd. dipper and caterpillar mounted was used. This excavation was about $1\frac{1}{2}$ miles long and averaged 25 ft. in width, with side slopes on the up-hill side of 1 to $1\frac{1}{2}$. The material was loose boulders overlying cemented gravel, chalk rock, and solid ledge. The excavation ran about 5 to $8\frac{1}{2}$ cu. yd. per lineal foot, and all material was cast to the side for fill. The shovel graded 7,884 lin. ft. at an average rate of 60 ft. per day. This is equivalent to about 450 cu. yd. per 8-hr. day. A four-man crew operated the shovel. All of the material was blasted ahead of the shovel.³

A street-grading job involving 21,500 cu. yd. was handled by a small revolving shovel with $\frac{3}{4}$ -yd. dipper mounted on traction wheels and loading into $1\frac{1}{2}$ -yd. dump wagons. The average haul was 1,000 ft. This cut was 3,500 ft. long and ran from 2 to 15 ft. in depth. The material was mixed sand and gravel, mostly sand. The work took 55 working days of 8 hr. each. The average output was 391 cu. yd. per day, and the best run for a 5-day period was 611 cu. yd. per day. Seven wagons handled the hauling. This work cost 22.4 cts. per cubic yard. The labor rates were: foreman \$4 day; shovelman, \$6 day; fireman, \$2.50 day; 11 laborers at \$2.50 day; seven teams at \$5 day; coal cost \$5.05 per ton at the shovel.⁴

¹ *Excavating Eng.*, April 1925.

² *Eng. Contr.*, July 19, 1916.

³ *Eng. Contr.*, June 7, 1916.

⁴ *Eng. Contr.*, June 7, 1916.

A very shallow grading job was handled by a revolving steam shovel with $\frac{5}{8}$ -yd. dipper. Here the cut did not exceed 18 in. in depth and it extended for 1.6 miles. The total excavation was 17,704 cu. yd., all in earth. The material was loaded and hauled in dump wagons, the haul averaging $\frac{1}{2}$ mile. Often the shovel had to wait 2 or 3 min. for wagons. The average output was 330 cu. yd. per 10-hr. day, and the best day's run was 477 cu. yd. The job took 54 working days, and in this time $25\frac{1}{2}$ hr. were lost due to rain and other causes.¹



FIG. 22.—Small caterpillar-mounted steam-shovel dragline.
The machine is equipped as a shovel in this view (see Fig. 23).

A light electric shovel equipped with a $\frac{5}{8}$ -yd. dipper and mounted on car wheels, with auxiliary traction wheels, was used on light excavation for street-railway track. The material was loaded on cars. During twelve 10-hr. shifts, the average output was 450 cu. yd. per shift. The shovel crew consisted of an operator and four laborers.²

On the Pacific Highway, near Seattle, Wash., a small gasoline shovel successfully handled 65,000 cu. yd. of grading, most of which was light work, except for one heavy cut of about 30,000

¹ *Eng. Contr.*, June 21, 1916.

² *Eng. Contr.*, July 19, 1916.

cu. yd. The material was earth and loose rock. The rock was drilled and shot to loosen it up. The cuts were 28 ft. wide from shoulder to shoulder. The shovel used was a 25-ton machine, caterpillar mounted, equipped with a $\frac{3}{4}$ -yd. dipper, and it loaded motor trucks. The average haul was about 600 ft. The machine worked two 10-hr. shifts per day and averaged 500 cu. yd. per shift with two trucks hauling. The hauling equipment was not sufficient and limited the output of the shovel. This shovel also did all the grubbing of stumps along the right



FIG. 23.—Small caterpillar-mounted steam-shovel dragline.

This is the same machine shown in Fig. 22; the shovel boom and dipper have been replaced by a 40-ft. dragline boom and $1\frac{1}{2}$ -cu. yd. bucket.

of way, piling the stumps for burning. It could do 1 acre of grubbing per 10-hr. shift. The crew consisted of two men, a runner and a helper. The gasoline consumption averaged from 25 to 30 gal. per shift on the excavation work.¹

On a street repaving job in Omaha, Neb., a small revolving gasoline shovel was used to rip up and remove the old pavement, which consisted of an asphalt surface layer on a 12-in. concrete base. The machine used was a 25-ton shovel, caterpillar mounted, with a $\frac{3}{4}$ -yd. dipper, which loaded 5-ton trucks.

¹ *Excavating Eng.*, January 1925.

Three thousand cubic yards of this old pavement was torn up and removed at the rate of 300 cu. yd. per 10-hr. day.¹

A small Diesel-powered shovel was used in the northwest to handle roadbed construction for narrow gage railroads in the logging district. All excavation was earth, and the cuts and fills averaged 2 ft. in height. Much clearing had to be done, and the shovel handled the grubbing of stumps. The machine was of 25-ton size, caterpillar mounted, equipped with a $\frac{3}{4}$ -yd. dipper. It was operated by two men, a runner and a helper. The cost of operation per 8-hr. day was as follows:

Operator's wages.....	\$10.83
Helper's wages.....	6.00
Fuel oil.....	1.20
Lubricating oil and grease.....	.35
Cable charge.....	.25
Total.....	\$18.63

From 200 to 300 lin. ft. of roadbed was constructed per 8-hr. day by this machine.²

In Indiana County, Pennsylvania, a highway job of some size was handled by two 25-ton Diesel-powered revolving shovels, caterpillar mounted, and having $\frac{3}{4}$ -yd. dippers. Here the cutting was light, and the material was a mixture of earth, shale, and loose limestone. It was not necessary to shoot this material. With a haul of from 500 to 2,500 ft., and loading into $1\frac{1}{2}$ -yd. wagons, these shovels averaged from 500 to 750 cu. yd. per 10-hr. day each. The contract price for excavation was \$1.05 per cubic yard, unclassified. Fuel consumption on this job averaged 15 gal. of fuel oil per shovel per day.³

Large Shovels in Stripping Work.—One method of handling stripping operations in the bituminous coal fields where revolving shovels are used is to open up the first or box cut with a smaller machine or by other means; then start the stripping machine (the large shovel) in a straight line across one side of the tract in a through cut, dumping the spoil on the surface. The large machine returns in a parallel cut, dumping the spoil from it into the first cut, from which the coal has been removed meanwhile by another shovel or by hand. When the excavated

¹ *Excavating Eng.*, May 1925.

² *Excavating Eng.*, February 1926.

³ *Excavating Eng.*, January 1925.

material is to be hauled away, a track is laid on the surface of the ground along one side of the tract and the shovel cuts down-grade along the track until it reaches the maximum depth at which it can load overhead. Then it digs along on the level thus reached to the end of the tract. When the first cut is completed for the length of the stripping, the track is moved down to this cut and the shovel cuts downgrade again alongside the track to its loading limit depth. This process is continued until the shovel reaches the coal, when the track is laid in the same cut with the shovel for the rest of the work.

Near Dawson Springs, Ky., large revolving steam shovels were used for stripping the overburden from an extensive coal deposit. At this mine the overburden averaged 30 ft. in thickness, of which the upper 10 ft. was clay, underlain with about 20 ft. of blue shale. A revolving shovel of very large size was used, equipped with a 6-yd. dipper and 85-ft. boom. This machine took out cuts of 50-ft. width and dug up the shale without difficulty. When the shale strata exceeded 20 ft. in thickness it was loosened by shooting. This shovel was operated on two 10-hr. shifts per day and its output over a considerable period of time averaged 2,250 cu. yd. per shift or 4,500 cu. yd. per day.¹

Extensive stripping operations are being carried on in connection with the mining of large brown coal deposits near Melbourne, Australia. The overburden on these deposits is composed of sand, sandy clay, and gravel, and averages about 28 ft. in thickness. Most of the work is being handled by two large revolving steam shovels, one equipped with a 2½-yd. dipper, 60-ft. boom, and 38-ft. dipper handles, and the other having a 3½-yd. dipper, 75-ft. boom, and 48-ft. dipper handles. Both machines are truck mounted.

After an inclined cut was carried down to the surface of the coal bed, largely by hand excavation, one of the shovels was assembled and started to work in the cut. This shovel took out a box cut as wide as it could dig for a distance across the proposed cut of 600 ft. Additional cuts were made paralleling this first cut, and the shovel worked down to the surface of the coal, clearing all the overburden as the work proceeded. Later the second shovel was put to work. The overburden material was transported by means of a belt-conveyor system, resting on the original ground level. The main conveyors ran parallel to the face of the cut

¹ *Excavating Eng.*, April 1926.

and the shovels loaded into feeders which carried the material to the conveyors. The shovels were advanced by 35-ft. cuts.

In a 6 month's period the $2\frac{1}{2}$ -yd. dipper machine averaged 3,000 tons of overburden per day, working 24 hr. a day for 6 days a week. The larger machine averaged 4,200 tons per 24-hr. day. The fuel used was a briquetted coal made at the job.¹

On the construction of the Niagara Power Canal in Ontario, three 175-ton revolving electric shovels were used for the high lift work on dry-earth excavation. The earth cut was 162 ft. wide and the depth ranged from 50 to 145 ft. The shovels used were equipped with 90-ft. booms and 8-yd. dippers. They moved an average quantity of 85,000 cu. yd. each per month, loading on cars at an average height of 86 ft. above the shovel rails, and working one 10-hr. shift per day and no Sundays.²

Miscellaneous Excavation.—A 25-ton revolving steam shovel with $\frac{7}{8}$ -yd. dipper dug a foundation pit for a large building in New York. The tract excavated was 900 ft. long, 140 ft. wide and averaged 25 ft. in depth. The total amount of earth removed was 120,000 cu. yd., consisting of sand, gravel, and loam. Hauling was done by ten 5-ton motor trucks, which hauled an average load of 3.8 cu. yd. each. The trucks hauled up a 5 per cent grade out of the pit and then $5\frac{1}{2}$ miles to the dump. On this job 53,000 cu. yd. were disposed of in 165 9-hr. shifts, the average output per day being 320 cu. yd.³

A sewer trench 3 ft. wide and averaging 15 ft. in depth was excavated and backfilled by a small revolving steam shovel mounted on traction wheels. The material was shale which required shooting, overlaid with clay. The shovel was equipped with a 30-ft. dipper stick designed for trenching work. The shovel dug a length of trench, then the pipe layers followed with the pipe, after which the shovel backfilled the trench with material taken from ahead. Working 5 hr. a day, the shovel averaged 50 lin. ft. of trench or 83 cu. yd.⁴

In connection with the development of a large park on the west side of Chicago, a lagoon covering 12 acres was constructed. Excavation for this lagoon was handled by two 15-ton revolving steam shovels, equipped with $\frac{3}{4}$ -yd. dippers. The material was

¹ *Excavating Eng.*, November 1926.

² *Eng. Contr.*, Dec. 18, 1918.

³ *Eng. Contr.*, July 12, 1916.

⁴ *Eng. Contr.*, Dec. 11, 1918.

a hard clay, and the excavation had an average width of 125 ft. and an average depth of about $6\frac{1}{2}$ ft.

The following is a 5 months' record for one shovel which loaded into dump wagons. Most of the cuts were from 5 to 6 ft. deep and from 170 to 250 ft. long.

Month	Actual time, days	Loads per day	Cubic yards per 9-hr. day
May.....	$11\frac{1}{4}$	630	441
June.....	$17\frac{1}{3}$	987	680
July.....	$24\frac{1}{2}$	693	485
August.....	$26\frac{1}{2}$	954	668
September.....	$22\frac{1}{3}$	840	588

The second shovel loaded into $1\frac{1}{4}$ -yd. dump cars, hauled in 5-car trains by a team of horses. One cut taken out by this shovel averaged 8-ft. in depth. The record for two months follows:¹

Month	Actual time, days	Loads per day	Cubic yards per 9-hr. day
August.....	$19\frac{2}{3}$	872	610
September.....	$22\frac{2}{3}$	968	678

Excavation and backfilling for a small pipe-laying and sewer job were handled by two small revolving steam shovels, mounted on traction wheels and equipped with $\frac{7}{8}$ -yd. dippers. A water main was laid in a trench with 7-ft. cover, and an 8- to 12-in. sewer was laid with cover varying from 8 to 22 ft. The material was loose sand with some gravel, and some water accumulated in the trench. The excavation was carried close to grade by the shovels, and then finished by hand. The material was deposited over the completed sewer behind the shovels. The trench was excavated with side slopes of about 1 to 1 and no sheeting was used unless the depths exceeded 15 ft.

For depths of from 8 to 22 ft., where sheeting was used for the lower 4 to 6 ft., the shovel progressed from 18 to 25 lin. ft. per 10-hr. day. The shovel was idle part of the time waiting on the trench men and pipe layers. For depths of from 9 to 12 ft.,

¹ *Eng. Contr.*, Dec. 20, 1916.

as much as 145 ft. of pipe were laid per day, progress depending on the shovel. The labor cost on this work per 10-hr. day was:¹

1 foreman.....	\$ 7.50
1 shovel man.....	9.00
2 pipe layers.....	13.00
1 fireman.....	6.50
2 laborers.....	5.00
1 team.....	10.00
Total.....	\$51.00

¹ *Eng. Contr.*, Dec. 10, 1919.

CHAPTER V

THE DRAGLINE EXCAVATOR

Of all the different types of excavating equipment in general use, the dragline excavator is now recognized as being best fitted to meet the requirements of many big jobs of excavation. Twenty years ago it was practically unknown. Today it is in general use in all parts of the United States wherever big construction work is in progress. It is so well adapted to so many different kinds of work that it is coming into demand more and more as its possibilities are being recognized. Its long reach enables it, in many cases, to deposit material direct from excavation into fill or waste bank, in one operation. Revolving on its base through a full circle, it can dig or dump anywhere within a radius determined by the length of its boom. It can build its own trackway ahead, and clean up behind as it goes. In many cases it can handle heavy loads as well as a derrick or locomotive crane. It can load cars almost, if not quite, as well as a steam shovel. It has been used successfully in rock cuts. It can pull down a bank standing high above the level at which it is working, and can excavate a pit far below where it stands. It can dig under water almost as well as in the dry. It can strip a gravel pit, placing the overburden off to one side, and then be ready to handle the gravel itself as required. To cross a river it simply builds a peninsula to serve as a track way, then moves out on to it, takes up material from behind and deposits it ahead until the peninsula becomes a moving island, on which the machine travels on across until the other shore is reached.

DEVELOPMENT OF THE MODERN MACHINE

The Dragline Derrick.—Prior to the time when the modern dragline excavator came into general use, many construction men had made use of movable stiff-leg derricks equipped with drag buckets, for handling certain jobs where conditions happened to be favorable for that type of equipment. Even today it is not uncommon to see such outfits performing certain work very

economically. Figure 24 shows an installation of that sort. A section of low embankment, $1\frac{1}{2}$ miles long, for a portion of the relocation of an electric railway was to be built from side borrow on either side. No dragline machine was available for the work at the time it was desired to do it. The two stiff-leg derricks shown in this view were equipped with drag buckets, mounted on skids and rollers, and handled this job practically as well as a dragline machine could have done it. They backed out across the flats, side by side, building the fill as they went. Much of



FIG. 24.—Dragline derricks building embankment.

This embankment, a mile and a half long and containing 65,000 cu. yd. of material, was built by these machines from side borrow at a cost of 27 cts. per cubic yard,⁷ including the cost of equipping the derricks for dragline work.

the material in the borrow pits was taken from below ground-water level, which in this case was close to the ground surface. The total quantity in this fill was 65,000 cu. yd., which was placed at an average cost of 27 cts., including equipment depreciation and all filed overhead, with labor at 40 cts. per hour and other wages in proportion.

The swing of the boom in this case is only about 250 deg. which is a serious limitation for all-around work, compared with the up-to-date dragline, but it illustrates very well the first step in the development of the modern dragline excavator, and many jobs may still be handled efficiently with this type of equipment.

Figure 25 shows one of the same machines excavating gravel for concrete, and is another illustration of an economical use of these improvised dragline derricks. The hopper used for loading wagons is also on skids, and can be moved ahead by the machine as its borrow pit is extended. Stripping of the pit, as required, is handled by the same machine in advance of the main excavation, as the machine is moved back, strip by strip, the overburden



FIG. 25.—Dragline derrick loading gravel.

The gravel from the borrow pit is dumped into the loading hopper, through which it is fed by a hand-operated gate into dump wagons. The hopper itself is on skids and rollers and is moved ahead by the machine as the borrow pit is extended. Stripping of the pit as required is handled by the same machine in advance of the main excavation.

being dumped off to one side out of the way, or loaded into wagons and hauled to wherever it may be used economically.

The Timber Machine.—The next step in the development of dragline excavators, was a machine similar to the modern dragline, except that it was built of timber, framed and assembled on the job. Except for the center casting, which had to be cast especially for the purpose, these machines were assembled from

standard equipment parts, timber from the nearest source of supply, turntable and dollies from one place, boiler and hoist from another, swinging engines, derrick castings, sheaves and lines, all fitted up to the requirements as well as possible from standard parts originally built for other purposes. These machines, at least those of them which were intelligently assembled, were very successful—so much so, that the manufacture of standard dragline machines was soon undertaken, and



FIG. 26.—Modern dragline excavator.

This is a steel-frame machine mounted on skids and rollers, equipped with an 85-ft. boom and a $4\frac{1}{2}$ -yd. bucket. The whole machine may be revolved through a complete circle on the turntable just below the floor of the house. The bucket is loaded by being pulled toward the machine by the horizontal cable leading in to the foot of the boom. The hoisting cable from the end of the boom lifts the bucket to the desired height, the bucket being so hung that it holds its load until the tension on the drag cable is released, when the nose of the bucket drops and the load is discharged. Thus a load may be picked up at any point within reach, swung around and dumped at any other point within reach of the boom.

naturally, a more finished and more durable machine was produced.

The Modern Machine.—As compared with the equipment first described, the modern steel-frame dragline excavator shown in Fig. 26 is a long step in advance. This is an electric machine equipped with an 85-ft. boom and a $4\frac{1}{2}$ -yd. bucket, and illustrates the highest development in the dragline machine at the

present time. The boom does not swing, as in the case of the dragline derrick, but is fixed with reference to the body of the machine, thus permitting the hoist and drag cables to come straight in to the drums, and doing away with the constantly changing horizontal angles caused by a swinging boom. But the whole machine may be revolved through a complete circle, on the turntable just below the floor of the house. Thus its load, picked up at one point, may be swung around and dumped at any other point within reach of the boom. This machine is mounted on skids and rollers; truck mounting may be had if preferred. Sectional mats made up of heavy timber are laid ahead on a prepared grade, to give firm and even bearing for the rollers. The grade is prepared by the machine itself, with a minimum amount of hand work by the two track men who are a part of the regular crew. As the machine moves ahead the mat sections left in the rear are picked up by the machine by means of eye bolts and slings, and swung around into place ahead, where they are spotted by the track men. The bucket is then thrown out ahead, takes a bite into the ground, and the machine pulls itself ahead by taking in on the drag line, the rollers being manipulated by the track men, who also bring the rollers ahead from the rear as needed. When a truck mounting is furnished with these machines a self-propelling mechanism is usually a part of the regular equipment. In that case, sections of rail are mounted on the mats, and the mat sections must be set with more care, of course, in order to hold the gage.

Revolving Mechanism.—The machine just described is revolved by means of a rack-and-pinion mechanism and can be turned in either direction any number of times, without limitation. There is another type of revolving mechanism which is still in common use, but is gradually being displaced by the more efficient rack-and-pinion type. It is an adaptation of the bull wheel, the swinging being accomplished by means of two cables having dead ends on the perimeter of the turntable, and leading around it in opposite directions. These cables run to drums, on the platform, which are operated by the swinging engine. While the machine thus equipped can revolve practically a full circle, it must return in the direction from which it has revolved. While ordinarily this is no great disadvantage, it is a serious limitation in some cases. The cable-swing machine is lighter and somewhat cheaper than the other.

Boom Suspension.—The dragline boom may be raised or lowered to any position within working range by means of the boom line, which passes over a sheave at the top of the A-frame down to a drum on the platform, which may be operated by power (on the larger machines), or by hand (on the smaller machines). It is not raised or lowered while working. For ordinary work it is set at an angle of about 30 deg. with the horizontal. It requires only a few moments to change it to any position most advantageous to the work in hand.

Mountings.—For the smaller machines, caterpillar mounting is most desirable, as it gives great flexibility and makes moving a quick and simple operation. It also does away with the necessity of track men to help handle and spot the mats. As the machine moves under its own power it simply has to level off a roadway for itself, and can move with almost no delay to digging operations. It can also move very quickly from one point to another on the job and may thus be available for other service than ordinary digging, on short notice. Figure 27 shows a machine on caterpillar mounting. It is not uncommon for such a machine to throw up a piece of track embankment, unload a car of coal, move a piece of track on the spoil bank, and load a car of scrap, with so little loss of time moving from job to job that all of these operations, or other similar ones, might easily be performed in one shift.

But the caterpillar mounting has its limitations, and it has not yet been worked out successfully for the larger machines; on these either skid-and-roller or truck mounting is preferable. The former is the more common, and is very satisfactory for machines of medium size. These machines are not required to move as often as the smaller ones. They are usually installed for the purpose of carrying on a job of considerable size without interruption, and are not expected to move very far from job to job without being dismantled. The skid-and-roller mounting lends itself very well to meet most requirements of machines of that size.

The larger the machine the more rollers are required to support it. For the large machines, therefore, the number and weight of rollers required gets to be a handicap, and truck mounting is more satisfactory. The self-propelling feature, in many cases, is a marked advantage. That, of course, is impossible with skid-and-roller mounting.

The "walking" dragline is so named because of its novel method of locomotion. When working, the machine stands on a large circular base. When ready to move it swings around to the proper position, then throws into gear a heavy steel shaft which passes through the machine from side to side. On each end of the shaft is a mammoth wheel segment which, when revolved, acts as a cam to lift the whole machine off the ground and forward about 8 ft. Each wheel segment carries with it, by

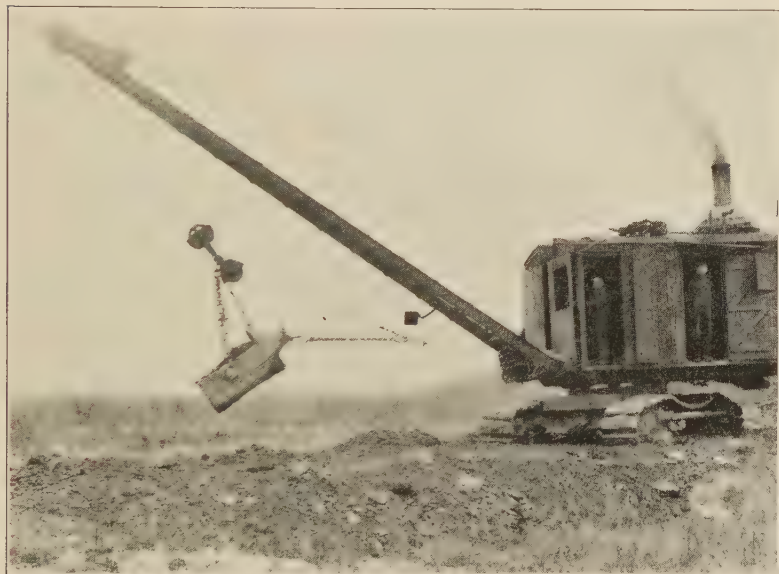


FIG. 27.—Small dragline excavator on caterpillar traction.

For the smaller machines this caterpillar mounting is desirable as it makes moving a quick and simple operation. The machine moves under its own power, and as it prepares its own roadway, moving can be done with practically no delay to digging operations. A machine thus equipped can also move quickly from one point to another some distance away.

means of carrying beam and chains, its own mat, or shoe, which drops into place on the ground, automatically, as the wheel segment comes down. And so the machine walks forward step by step, with its weight carried first on the center base then on the side shoes, very much like a man on crutches. Obviously, by the simple expedient of swinging around to the proper position when resting on its center base, this machine can start off in any direction, or can turn corners in one operation, since the

wheel segment and side shoes swing with the body of the machine. This is an advantage of the walking dragline over other types.

Power.—The power for operating the dragline machine may be either steam, electric, oil, or gasoline. Steam or electric is standard for machines of all sizes. Gasoline and oil engines are now used extensively on the smaller machines. The selection of power equipment necessarily depends on local conditions, such as transportation, hauling, and loading onto machine, for coal, and availability and character of supply for electric power.

Bucket.—Various types of scraper buckets have been built for dragline machines; one in common use is the Page bucket, illustrated in Fig. 28. For operating this bucket both the hoist line and the drag or load line are used. The bucket is so hung that

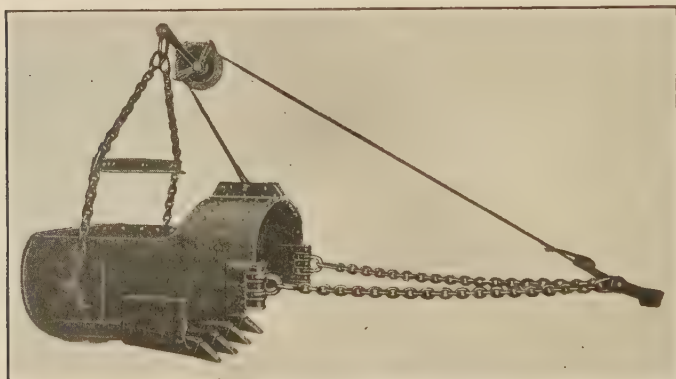


FIG. 28-A.—The Page bucket.

This is a common type of bucket used with dragline machines.

when on the ground and being pulled in toward the machine by the drag line, it digs in and loads itself. Then the hoist line is put into play and lifts it out of the ground. By means of the short piece of cable running from the bail of the bucket over the sheave, at the hoist connection, and out to the drag connection, the bucket is held in a horizontal position as long as the drag line is kept taut. When the bucket is hoisted and swung to the desired position the drag line is released and the bucket dumps. These buckets are equipped with manganese-steel lips, and except for soft material, manganese-steel teeth are also used. These teeth are replaceable and need to be renewed frequently in hard digging.

The bucket shown in the illustration has a flat bottom. It has been found that in rock excavation a rounded bottom is preferable, as the bucket is less likely to turn over in loading. Some operators prefer the rounded bottom for general use. It cleans itself more easily in sticky material, may be made somewhat lighter for the same strength, and is better for trimming slopes and work of that sort. It loads in less distance than a flat-bottomed bucket. In fact, in many ways it has similar advantages to those of a round point over a square point shovel.

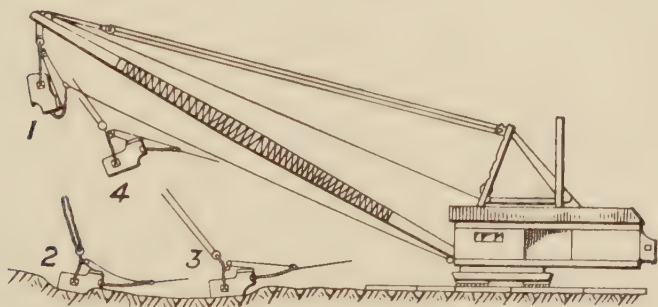


FIG. 28-B.—Diagram showing the cycle of operations using the Page bucket.

GENERAL FEATURES OF OPERATION

Crew.—For ordinary work with a skid-and-roller machine a dragline crew consists of an operator, a fireman or oiler (on steam or electric machine respectively), and about three ground men who level up ahead for mats, spot the rollers for moving, look after water lines, load on coal, or look after electric cables, moving transformers, etc. The smaller machines on caterpillar mounting get along with only one or two ground men and sometimes none at all. On some of the very small machines the operator does his own firing when working conditions permit. The matter of adapting the size of the crew to the work at hand is one that needs some study on most jobs. It often happens that under favorable conditions considerable economy can be effected by putting on an extra man or two, and thus increasing the output of the machine.

Power Consumption.—Coal consumption per shift varies from 1 or $1\frac{1}{2}$ tons for the small machines, to 4 or 5 tons for the large

ones. The consumption of electric current will average somewhere near 1 kw.-hour per cubic yard for good material under fairly favorable conditions.

A comparison was made between two large machines, one steam and one electric, working side by side on the same work, over a 4-month period. During that time one machine excavated and loaded 283,000 cu. yd., and the other 277,000 cu. yd. of gravel. The steam machine averaged 4.1 lb. of coal per cubic yard and the electric 0.86 kw.-hour per cubic yard. These were large machines, working under fairly favorable conditions.

A smaller steam machine, on 30,000 cu. yd. of good digging, averaged $7\frac{1}{2}$ lb. of coal per cubic yard. Obviously coal consumption per cubic yard will vary more than that of electric power since fires must be kept up whether the machine is digging or not, while electric power is used only when the machine is actually working. Moreover the condition of boilers and engines is more likely to be allowed to run down than is that of corresponding parts of the electric machine.

A large electric machine in 1 month on channel excavation moved 52,000 cu. yd. with a power consumption of 1.05 kw.-hours per cubic yard. The same machine during another month on better digging took out 88,500 cu. yd. with a power consumption of 0.92 kw.-hour per cubic yard. This machine averaged 0.90 kw.-hour per cubic yard for a period of 16 months, during which time 980,000 cu. yd. of material was moved. Another similar machine under less favorable conditions used 1.40 kw.-hours per cubic yard during one month moving 25,000 cu. yd., and 1.17 kw.-hours per cubic yard during another month when 69,000 cu. yd. were moved.

A large electric machine on rather favorable channel excavation work, loading into cars, used 0.75 kw.-hour per cubic yard during one month when 73,000 cu. yd. of material were moved. This same machine averaged 1 kw.-hour per cubic yard over a long period covering the handling of 2,500,000 cu. yd. Another on borrow-pit excavation loading into cars averaged 0.65 kw.-hour over a long period.

A large electric machine taking out 600,000 cu. yd. of borrow pit excavation averaged 0.65 kw.-hour per cubic yard. Another of the same type taking out 300,000 cu. yd. of channel excavation averaged 0.80 kw.-hour. This same machine on 61,000 cu. yd. of more favorable work, averaged 0.61 kw.-hour per cubic yard.

Cable Expense.—Cable expense is a larger item of operation cost than is often supposed. Drag cables on the larger machines are good for not more than about 40,000 to 50,000 cu. yd. on an average, and on bad work or with careless handling may easily get down to 5,000 cu. yd. A fair service for hoist cables is 60,000 to 70,000 cu. yd. This item of expense will vary greatly from month to month, especially that for drag cables, as their life depends upon so many varying conditions and circumstances.

The boom fall is practically a stationary line and seldom needs replacement, because this line is used as a running line only when the boom is being raised or lowered, which is not often. Strength and durability are the principal considerations. The rope commonly used for this purpose, on most machines, is a 6 by 19 improved plow steel, hemp-center rope. The same rope, with wire center or wire-rope center, is recommended for larger machines.

In order to obtain definite information regarding cable wear under actual working conditions service records were kept for both drag lines and hoist lines on several dragline excavators used by The Miami Conservancy District during its operations in connection with the construction of the Miami valley flood control works.

Many different makes and types of cable were used more or less extensively, and for experimental purposes service tests were made on many cables of special construction, supplied by various manufacturers for that purpose. Every effort was made to secure records of each line used on each of the larger machines, and the records were checked up frequently to make sure that the information obtained would be reliable. It was hoped that an analysis of such records would bring out some worthwhile information on the subject, and might lead to a type of construction which would give better service and lower cable costs on future work. The result of this effort was somewhat disappointing, in that it did not bring out any one type of rope which had an outstanding advantage over all others. A great deal was learned, however, and by no means was the effort wasted, but the field is still open, because the selection of the best wire rope for drag-line purposes is still to some extent a matter of personal preference.

Even with carefully compiled records, it is difficult to make reliable comparisons of cable wear between two machines, or

between two makes of cable on the same machine, the undeterminable factors are so numerous. The human equation as expressed in the skill and temperament of the operator; the care given the machine; practically undiscoverable faults, like a sheave slightly out of line on its pinion; may have more effect on cable wear than the type of machine or type of cable. This is more marked in the case of the drag cable. The character of work being done; the maximum pull of engine and motor; the diameter and type of drums; the design and construction of fair leads; the depth of cut and the consequent bend of the line over the fair-lead sheaves; the possibility of kinks and cuts from sharp rocks, and wear from dragging through sandy material; all have a marked effect on the life of a drag cable. As a matter of fact, the records obtained show clearly that a great many drag cables are not worn out at all, but are broken or cut before they hardly show signs of ordinary wear, and that the ultimate life of these lines is realized in only a comparatively few cases. While an operator is expected to use ordinary care in handling his bucket and line, his principal job is to get out the yardage, and a drag cable more or less is of small consequence compared with the steady output of the machine. In other words, while the selection of the most suitable cable for drag-line purposes is worth study, and may have considerable effect on unit cost of operation, there is very little that the operator is warranted in doing to save the cable at the expense of output, outside of ordinary care, avoiding kinks, severe jerks, hard pulls when the bucket is stuck, or continual dragging over a sharp obstruction that might easily be removed.

So, in studying the many records that were obtained it has become evident that the conclusions as to the best type of cable are not as obvious as might be desired. The final analysis of these records contains only the rope used on the larger types of machines, because since various sizes of machines were in use on this job, it was customary to use for drag lines on the smaller machines, the serviceable portions of discarded hoist lines from the larger machines.

One thing is evident, and this bears out the recommendation of manufacturers, that for both hoist and drag lines, Lang-lay construction is best. Lang-lay construction means that the lay of the wires in the strand and of the strands in the rope are both in the same direction, giving increased distribution of serviceable

wear and greater resistance to direct pull. In ordinary cable, known as "regular" lay, the twists of the wire in the strand, and of the strands in the cable, are in opposite directions.

Hoist Line.—The hoist line passes over the sheaves on the end of the boom and at the bucket, as well as over the hoist drum, is used continuously as a running line, and therefore requires flexibility. For this purpose a hemp center rope is desirable. The hoist line is not subject to the shocks or severe service that the drag line is, but nevertheless, the continual running over the sheaves means hard service and makes the cost of replacing hoist lines a considerable item. Improved plow steel is none too good for this class of service. The standard 6 by 19 rope gives the required combination of strength and flexibility. Nothing in the records under discussion leads to any better selection for hoist lines, for machines of any size, than the standard 6 by 19, improved plow steel, hemp-center, Lang-lay rope. The size of rope for any size or type of machine should be taken from the manufacturer's catalog.

Drag Line.—When it comes to drag cables, the records show that two things, namely, fair-lead construction and size of drums, have a great deal to do with the life of the cable. On one machine, where extremely poor records were made as to drag-line service, the length of life was increased 79 per cent by lagging the drums, increasing the diameter from 18 to 22 in., which was judged to be as much of an increase as the motor would stand. Unfortunately, it was not possible to do much towards improving the poor fair-lead construction on some of the machines used on this work; therefore, in selecting these records for the purpose of comparing cables, those applying to machines with poor fair-lead construction were eliminated.

As has been said, many different makes of cable were tried out, and many different types in addition to the standard types. Experiments were made on various special cables made up by different manufacturers for that purpose. These special cables were usually furnished free of charge, or with the understanding that the amount paid for them would depend on the amount of work they did. While some of these special cables seemed to have possibilities, none of them gave results that warranted their adoption in place of the standard 6 by 19 rope in general use, and none of the uses of the special ropes went beyond the stage of experimentation. Considering that a number of rope

manufacturers were enough interested in this thing practically to donate two or more lengths of cable for the purpose of experimenting, it may be assumed that the field in regard to these special cables was fairly well worked out, and that the standard 6 by 19 rope or something very similar, is at least as good as any type that has been suggested, up to the present time. In trying to find something better, the effort was to increase flexibility and wearing quality without sacrificing strength. The result usually was that either strength was actually sacrificed, or that the rope did not hold its shape.

Table III gives a summary of the life of drag cables on large machines engaged on earth excavation. This includes service records on 130 cables and covered a period of about 4 yr. The three different types of cables represented here are those which gave the best results on the job, all experimental lines being eliminated. There were also eliminated, in making up the figures, 17 of these cables which failed at less than 14,000 cu. yd., it being assumed (arbitrarily) that a failure at less than 14,000 yd. on these machines, and on this kind of excavation, was due to some accident which ought not to be considered in making comparisons between the cables. Such figures should be in the record however, and should be taken into consideration when arriving at the average length of life per cable throughout a job. The figures given in this table indicate that about 50,000 cu. yd. is a good average life for drag cable on such machines in earth excavation. Also that the difference between maximum and minimum records on this class of work is very great.

All these cables were Lang lay, and all were of improved plow steel. The 6 by 19 wire center was used as standard during the earlier part of the job, but later, the 6 by 19 filler wire construction, wire rope center, gave such excellent results, that it was adopted as standard during the latter part of the work. The filler wire construction is similar to the regular 6 by 19 rope, except that smaller wires occupy the spaces between the 19 larger wires in the strand, giving the rope a little more strength, but principally tending to make it hold its shape better. All the filler wire rope used on this job had an independent wire-rope center. The fact that the average of this cable falls slightly below that of the others may be due to the fact that the machines were older, and the sheaves more worn, and more often out of alignment; also perhaps because the work was speeded up more

and more, as time went on, and methods improved and output increased. The men on the job were strongly in favor of filler-wire construction, and it is a fact that the three highest records obtained, namely 165,000, 140,000, and 125,000 cu. yd. per line, were obtained on this type of rope on the same machine. Other ropes on this machine sandwiched in between these filler wire records, gave no better service than on other machines, indicating that the higher record was due to the rope, and not to any special excellence of the machine itself or its operators. So, in spite of the fact that the records do not show any advantage in favor of filler-wire construction, except that it yielded the three highest individual records, the opinion of many engineers is definite that this is the best type of construction so far devised for drag cable on the larger machines.

Table IV gives a summary of drag-cable service on two large electric machines working on earth excavation. In this table, records on 52 cables are included, 10 of which failed at less than 14,000 yd. and are eliminated in making up the figures. It should be said in this connection, that one of these machines was mounted on a scow during a good portion of the period covered by this record, loading material onto other scows, which meant unusually severe conditions for the drag cable, and additional work, because it was used frequently to pull the empty or loaded scows into desired positions, necessitating throwing of the bucket with corresponding jerks on the line. For that reason Table V is presented giving a corresponding record for drag lines used on one of these machines, which was working most of the time on straight excavating and casting. It was noted that the same size of drag cable gave longer service on machines with larger hoist drums, because there was less strain on the drag cable.

On rock excavation the wear is much more severe and the chances of accidental breaking of drag cables are much greater. Table VI shows a record of 20 drag cables used in rock excavation. This rock was alternate layers of limestone and shale. The cut was deep, reaching a maximum of 63 ft. below the level of machine (which is considerably more than the maximum depth given in manufacturers' tables), this condition increasing the strain on the drag cable and making things still more unfavorable than they would have been otherwise. But it is apparent that a drag cable in rock excavation will last not more than 15 to 20 per cent as long as it will in earth. It is interesting to note that not one

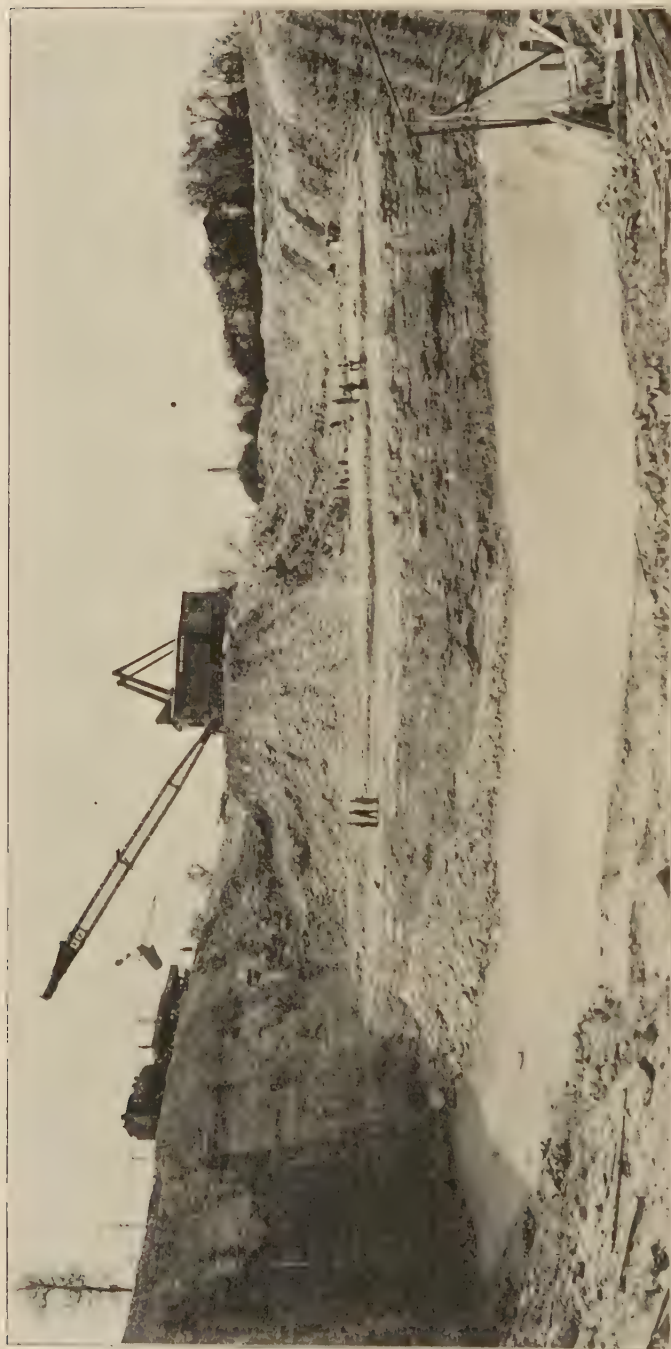


FIG. 29.—Rock excavation at Huffman dam.

At this point the dragline machine accomplished the unusual feat of moving 25,000 cu. yd. of rock from one setting, all of which was loaded into cars and hauled away. The deepest of the excavation was nearly 60 ft. below the base of the machine.

of the 20 cables included in Table VI gives a life of more than 9,000 cu. yd.

The highest records on the life of drag cable were obtained at the Huffman dam. Table VII shows a record of the machine at that point, on 11 cables in earth excavation and 5 in rock excavation. The earth excavation was river gravel and sand, with an overburden of loam and silt. The rock was alternate layers of limestone and shale. All this material was loaded into cars. Figure 29 shows the rock excavation in progress.

Care of Wire Rope.—A brief review of the District's practice in the handling and care of wire rope may be of value in suggesting ways of prolonging the life of these lines in service. Special care was taken in handling the cables at the central warehouse, that they might be delivered to machines in first-class condition. Cable was received from the manufacturers usually on spools; sometimes short pieces came in coils. In either case, before being cut for use it was rolled out straight, avoiding kinks, and measured to the length required. Before cutting, the cable was clamped on each side of the place to be cut, and then burnt off with torches. This prevented raveling of the strands or wire, and the slipping of either in the rope. All cable was kept clean and well oiled to prevent rusting. A drag cable wears most rapidly at the end next to the bucket. Where the cable length permitted, this worn part was cut off and the cable was turned end for end to secure maximum wear. But extra long cables could not always be used to advantage, as it was found desirable not to have the line so long as to require more than one layer on the drum when the bucket was pulled in close to the machine. Some machines are not designed for deep digging with that limitation in mind, and sometimes it cannot be avoided, but it always should be avoided if possible. Pulling and crowding the top layer over and into the lower one, under the strain of loading a bucket, results in undue wear and tear on the line. It was found also that a grooved drum, scored to the diameter of the cable, materially increased the life of the cable by preventing rubbing together of the coils. Oversize cable does not give results that might be expected, at least without complete change of sheaves and a suitable modification of drums.

Cable Costs.—The following figures show the influence of cable cost on the cost of operation of dragline machines. The figures cover the service record on a number of cables in each

case, and on separate machines, and include all cable used, regardless of premature failure.

COSTS OF DRAG CABLE

(Earth Excavation)

Description of cable: 1 $\frac{3}{8}$ -in. diameter, 6 by 19 improved plow steel, Lang-lay, filler-wire construction, independent wire rope center.	
Number of cables.....	90
Average length.....	169 ft.
Cost per foot.....	53.9 cts.
Cost per cable.....	\$91.09
Average life.....	44,300 cu. yd.
Average cost of cable per 1,000 cu. yd.....	\$2.06
Average length of life.....	21 $\frac{1}{2}$ days.

A similar record for hoist lines on several machines of the same size follows:

COSTS OF HOIST CABLE

Description of cable: $\frac{3}{4}$ -in. diameter, 6 by 19 improved plow steel, Lang-lay, hemp center.	
Number of cables.....	28
Average length.....	395 ft.
Cost per foot.....	18.6 cts.
Cost per cable.....	\$73.27.
Average life.....	60,000 cu. yd.
Average cost of cable per 1,000 cu. yd.....	\$1.22.
Average length of life.....	34 days.

The average life of these cables as shown in the foregoing, namely 44,000 cu. yd. for drag lines and 60,000 cu. yd. for hoist lines, are fair averages to use in estimating cable requirements for work of this sort on a long job. The average life of a hoist line may be taken to be roughly about 50 per cent longer than that of a drag line. The average cost of a hoist line per cubic yard of excavation is approximately one-half that of a drag line. The cost of wire-rope equipment is a large enough item in the cost of dragline excavation so that it is a matter of economy to secure the best rope possible for the purpose.

TABLE III.—SUMMARY OF LIFE OF $1\frac{3}{8}$ IN. DRAG CABLES ON MACHINES, STEAM AND ELECTRIC, ON EARTH EXCAVATION

Number of cables	Type	Maximum, cubic yards	Minimum, cubic yards	Average cubic yards	Average number of days
17	6 by 19 wire center.....	84,730	19,450	52,820	34
63	6 by 19 filler wire.....	165,000	14,409	50,530	21
33	6 by 25 flattened strand.....	90,820	15,000	42,580	19½

Cables Failing at Less Than 14,000 Cu. Yd. per Cable

- 8 { 6 by 19 wire center
6 by 19 filler wire
- 9 { 6 by 25 flattened strand

Note: All these cables were improved plow steel, Lang lay.

The filler-wire rope has an independent wire rope center.

The flattened-strand rope has a hemp center.

TABLE IV.—SUMMARY OF LIFE OF $1\frac{3}{8}$ IN. DRAG CABLES ON LARGE ELECTRIC MACHINES ON EARTH EXCAVATION

Number of cables	Type	Maximum, cubic yards	Minimum, cubic yards	Average cubic yards	Average number of days
3	6 by 19 wire center.....	75,100	41,300	62,100	43
18	6 by 19 filler wire.....	106,000	15,000	41,510	29
24	6 by 25 flattened strand.....	101,000	16,000	42,030	22

Cables Failing at Less Than 14,000 Cu. Yd. per Cable

- 3 { 6 by 19 wire center.
6 by 19 filler wire.
- 7 { 6 by 25 flattened strand.

Note: All these cables were improved plow steel, Lang lay.

The filler-wire rope has an independent wire rope center.

The flattened-strand rope has a hemp center.

TABLE V.—LIFE OF $1\frac{3}{8}$ IN. DRAG CABLES ON ONE LARGE DRAGLINE MACHINE ON EARTH EXCAVATION

Number of cables	Type	Maximum, cubic yards	Minimum, cubic yards	Average cubic yards	Average number of days
3	6 by 19 wire center.....	75,100	41,300	62,100	43
4	6 by 19 filler wire.....	106,000	22,000	69,100	50
13	6 by 25 flattened strand.....	101,000	16,000	48,350	25

Cables Failing at Less Than 14,000 Cu. Yd. per Cable

- 2 { 6 by 25 flattened strand.

Note: All these cables were improved plow steel, Lang lay.

The filler-wire rope has an independent wire rope center.

The flattened-strand rope has a hemp center.

TABLE VI.—LIFE OF $1\frac{3}{8}$ IN. DRAG CABLES ON DRAGLINE MACHINE ON ROCK EXCAVATION

Number of cables	Type	Maximum, cubic yards	Minimum, cubic yards	Average cubic yards	Average number of days
10	6 by 19 wire center.....	8,900	4,800	6,500	9
10	6 by 25 flattened strand.....	9,000	3,000	6,900	10

Note: All these cables were improved plow steel, Lang lay.

The filler-wire rope has an independent wire rope center.

The flattened-strand rope has a hemp center.

TABLE VII.—COMPARISON OF LIFE OF $1\frac{3}{8}$ IN. DRAG CABLES ON A LARGE ELECTRIC DRAGLINE MACHINE ON EARTH AND ON ROCK EXCAVATION

Number of cables	Type	Maximum, cubic yards	Minimum, cubic yards	Average cubic yards	Average number of days
Earth Excavation					
3	6 by 19 filler wire.....	165,000	125,000	143,300	56
8	6 by 25 flattened strand.....	75,000	15,000	49,400	26
Rock Excavation					
3	6 by 19 wire center.....	17,000	9,000	14,000	9
2	6 by 25 flattened strand.....	9,000	8,000	8,500	13

Note: All these cables were improved plow steel, Lang lay.

The filler-wire rope has an independent wire rope center.

The flattened-strand rope has a hemp center.

Supplies and Repairs.—Table VIII gives a summarized list of supplies and repair parts, and cost of shop work on a large electric dragline machine during a year's operation on river-channel excavation. This is of interest for two reasons: First, it shows the cost of certain items of supplies which are required in somewhat regular quantities, such as rollers, electric supplies, wire rope, grease, oil, waste, etc. Second, it calls attention to many replacements of parts which should be anticipated for a steady period of operation, not that all of these parts will need to be replaced each year; the $\frac{1}{6}$ flexible electric cable, for instance, was replaced only once during 5 yr. of work, but in place of those that carry over for a longer period, other parts not mentioned here will be needed, so that this list may be taken as a suggestion of what may be required, and it represents an important item of operating expense.

During this period the machine handled 513,000 cu. yd. of excavation. This is considered a fairly representative year as

far as output is concerned, and this particular list was selected because it also is considered fairly representative of the cost of upkeep of one of these machines in continuous service. It will be noted that a considerable portion of this expense is for expendable supplies, such as rollers, wire rope, repairs on bucket, etc., the cost of which will depend to some extent on the yardage moved during the period. The list includes all labor on repairs and upkeep outside of that furnished by the regular dragline crew.

TABLE VIII.—SUPPLIES, REPAIR PARTS AND LABOR ON REPAIRS AND UPKEEP FOR ELECTRIC DRAGLINE, DURING ONE CALENDAR YEAR

(Excavation during this period, 513,000 cu. yd.)

Supplies and Parts

Wood rollers— 94 at \$1.00	
259 at 0.95	
198 at 1.329	
196 at 1.61.....	\$ 919.66
Brake lining.....	695.12
$\frac{1}{4}$ flexible-wire cable (electric).....	549.70
Flexible copper wire.....	55.27
Electrical supplies.....	622.19
Wire-rope drag lines.....	\$1,533.99
Hoist lines.....	834.52
Miscellaneous.....	11.55
	2,400.06
Grease, oil, and waste.....	144.07
Tools.....	58.62
Fire extinguishers and lanterns.....	18.67
Motor bearing.....	13.50
Intermediate swing shaft.....	35.00
Vertical swing shaft rack pinion.....	175.00
Hoist friction blocks.....	23.25
Hoist drum, shaft, and gear.....	250.00
Hoist toggle crank, and lever.....	10.50
Hoist friction band with blocks.....	150.00
Jaw lever, etc., hoist drum.....	31.10
200 hp. stator for motor.....	1,200.00
Drag drum and gear.....	600.00
1½-in. drag chain (for bucket).....	96.96
Gear segment.....	100.00
Heating stove.....	18.52
Cradle base.....	30.00
Brake valve.....	19.65
Cross head.....	23.00
Adjustable bolts.....	82.14
Bronze bushings.....	125.51
Hoist drum shaft.....	197.00

TABLE VIII.—SUPPLIES, REPAIR PARTS AND LABOR ON REPAIRS AND UPKEEP FOR ELECTRIC DRAGLINE, DURING ONE CALENDAR YEAR—.

(Continued)

(Excavation during this period, 513,000 cu. yd.)

Supplies and Parts

1 swing shaft.....	28.91	
3 intermediate shafts.....	117.43	
6 large shackles.....	92.41	
176 1½-in. machine bolts.....	123.65	
Miscellaneous bolts, clamps, steel, etc.....	929.63	\$ 9,936.52

Shop Work

(Labor by regular dragline crew not included)

Repair hoist rotor on 200-hp. 440-volt motor....	\$ 10.84	
Repair hoist rotor on 200-hp. 440-volt motor....	43.90	
Repair 1 fan for slip ring end of 200-hp. rotor...	8.23	
Rebabbitt and bore one 5-in. motor bearing and one 3½-in. motor bearing.....	38.95	
Repair hoist rotor.....	14.65	
Repair rotor for 200-hp. motor.....	22.57	
Repair box for shipping rotor.....	8.33	
Repair phase straps on hoist rotor, 200-hp.....	100.50	
Repair 4½-yd. bucket.....	829.02	
Repair 200-hp. rotor.....	49.44	
Repair 200-hp. rotor.....	10.93	
Repair 200-hp. rotor.....	29.73	
Repair 200-hp. rotor.....	18.33	
Crane service handling 200-hp. rotor.....	3.87	
Repair air compressor.....	7.47	
Repair bronze slip ring.....	5.04	
Repair 200-hp. Westinghouse stator.....	147.69	
Load 200-hp. rotor on auto truck.....	6.91	
Repair 200-hp. rotor.....	125.75	
Take pinion off rotor.....	17.84	
Electrical work.....	79.52	
Install 5-hp. motor on air compressor.....	72.54	
Repair swing shaft.....	14.99	\$ 1,667.04
		\$11,603.56

Dismantling and Erection.—Below are given some costs of dismantling and erection as they were obtained on various jobs from time to time.

A large machine after being dismantled was hauled by motor truck through city streets, a distance of 3¼ miles, and then re-erected. The cost of dismantling was \$2,250, cost of hauling \$687, and the cost of re-erection \$4,880.

A steam machine was dismantled, hauled by truck over city streets, a distance of about $2\frac{1}{2}$ miles, and set up again for further work. In this case the cost of hauling was \$350, and the dismantling and installation cost \$3,316.

Another steam machine was dismantled, hauled about $\frac{1}{2}$ mile by truck and loaded on cars at a cost of about \$3,250. To handle this machine it was necessary to erect two derricks, one at the machine for dismantling, and one at the railroad siding for loading.

An electric machine was unloaded from cars and erected, by means of a derrick set up for the purpose, at a cost of about \$2,500.

Another was unloaded and erected at a cost of about \$3,300. The work was done by hand with the aid of gin poles.

Another was dismantled and loaded onto cars at a cost of \$1,250. In this case the machine stood alongside a railroad siding and a small steam shovel was used for dismantling and loading.

Another was dismantled and loaded, with the help of a guy derrick, for about \$2,250.

Another was dismantled and loaded at a cost of about \$1,950 of which \$100 was for freight on a locomotive crane.

A steam machine was dismantled and loaded with the help of a locomotive crane at a cost of \$430.

A small machine on caterpillars was unloaded from car and erected at a cost of about \$1,600.

Another on skids and rollers, was dismantled, hauled about 22 miles over good roads and erected, at a total cost of \$2,447, of which \$744 was for dismantling and loading on trucks, \$523 for hauling, and \$1,210 for re-erection. In this case a steam shovel was used for re-erection, for which a charge of \$160 is included.

Accuracy of Cutting to Grade. This depends largely upon the skill of the operator. For dry work a heavy drag built of timbers and old rails has been used successfully for finishing a grade. It was swung from the bucket and pulled over the surface by the dragline after the actual excavation had been done. A surface so finished was expected to show no variation greater than 6 in. from the proposed grade line. Figure 30 is a drawing of the drag used.

When digging under water, if the water level remains stationary, a variation of not over 1 ft. from established grades can be main-

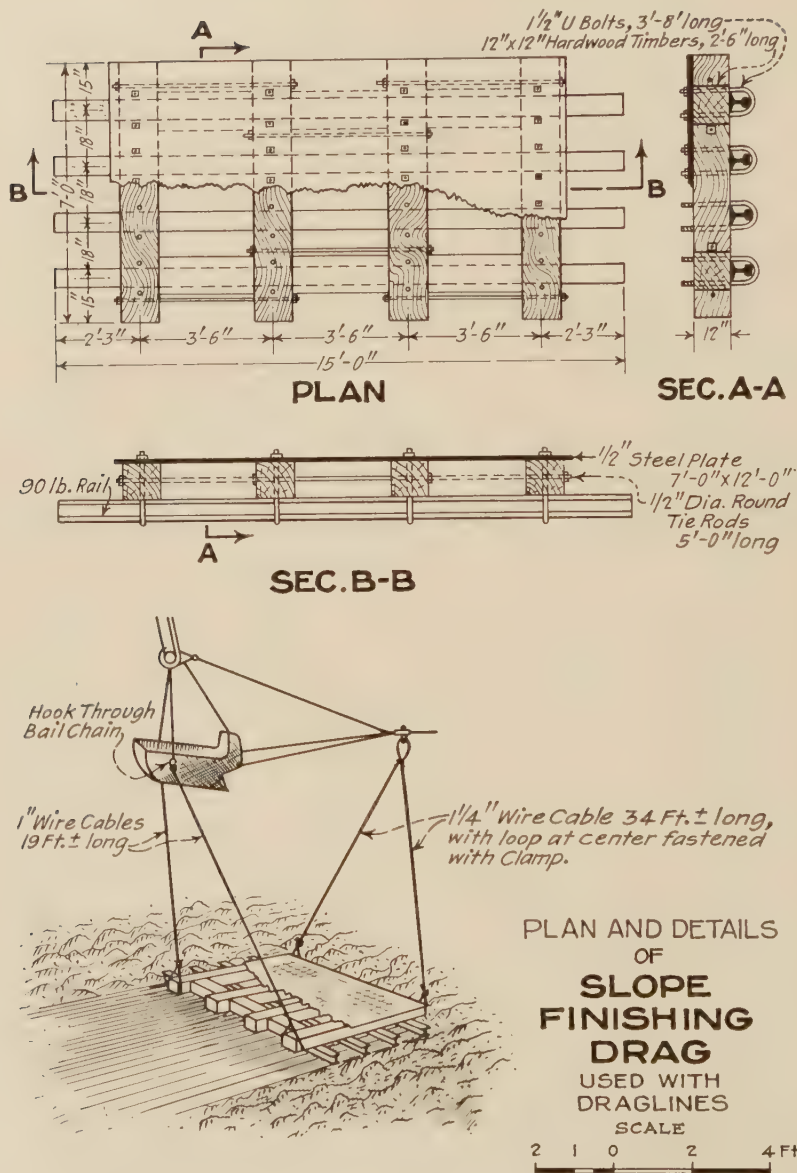


FIG. 30.—Drag for finishing cuts.

Cuts along a river channel were finished by suspending this drag from the bucket and pulling it over the surface, following the rough excavation.

tained. The operator can gage the depth below water by various distinguishable features on the bail chains of the bucket. When the water level is fluctuating to any extent, it is difficult for the operator to compensate properly for the varying depth and less accurate work will result. It has been noted that there is a tendency for the operators, when excavating below water, to dig a consistent overdepth of from 6 to 12 in. This may be due to the fact that on dragging in, the bucket is tilted with the teeth downward for a considerable distance before straightening off level, in which latter position the operator can gage his cut more accurately. This overdepth cutting can be lessened by lessening the cut 6 in. or so on the instruction sheets given the operator.

In excavating soft rock for later concreting operations, it is impracticable to dig closer than 1 ft. to grade, as the bucket teeth will pull and shatter the rock layers some distance back of the line of excavation.

Throwing the Bucket.—The width of cut per run for dragline excavators should usually be determined within the limit of reach of the bucket when hanging directly under the end of the boom. It is sometimes desirable, however, to reach out farther and pick up material that has slumped off or washed into the edge of the previous cut. An experienced operator can accomplish this by drawing in on the drag cable with the bucket suspended, then releasing the cable and allowing the bucket to swing out beyond the end of the boom before dropping. This process is known as "throwing the bucket." Observations taken while excavating from a river channel showed the possibility of throwing the bucket the following distances beyond the end of the boom:

Machine with 100-ft. boom, $4\frac{1}{2}$ -cu. yd. bucket.....	35 ft.
Machine with 60-ft. boom, $1\frac{1}{2}$ -cu. yd. bucket.....	20 ft.
Machine with 35-ft. boom, $\frac{3}{4}$ -cu. yd. bucket.....	10 ft.

Time of Swing.—The time required for making a complete operation—digging, swinging, and dumping—varies with the nature of material excavated, the angle of swing, depth of cut, height of dump, care necessary in dumping, etc.

Observations on several electric machines with 125-ft. boom and $4\frac{1}{2}$ -cu. yd. bucket digging under water, showed that they could dig, swing through an arc of 180 deg. and dump into a spoil bank in 50 to 55 sec., if the digging is in fairly loose gravel. The

same machines, digging loose dry material and swinging 45 to 90 deg., can complete the operation in 34 to 36 sec. An electric machine with 100-ft. boom and 3 cu. yd. bucket digging from a borrow pit and loading 12-cu. yd. dump cars, averaged for the round trip from 52 to 65 sec., depending on the angle of swing.

Crossing Rivers.—Many times during the course of various dragline operations it is necessary for the machine to make a river crossing. The ease with which that is accomplished with a dragline machine is notable, as compared with a similar under-



FIG. 31.—Dragline machine crossing river.

The crossing began at the far shore by building out a peninsula as a roadway for the machine, this work being done by the machine itself. The machine then rolled out on to the peninsula, picked up the material from the rear and placed it ahead, thus forming a moving island which gradually approached the other shore. In this view the moving island has just been joined to the shore, forming a trackway on which the machine will move out of the channel, clearing up the fill behind it as it goes.

taking with almost any other type of excavating equipment, many of which would have to make for the nearest bridge. It is accomplished by simply throwing out a trackway, in the form of a jetty, into the stream, running out upon it, and then, by taking up the material from the rear and placing it ahead, proceeding across on a moving island which eventually joins the shore on the other side and forms the trackway for leaving the channel. Figure 31 shows a large machine in the act of making one of these crossings. The machine is proceeding to the right, and

has just joined its moving island to the shore, forming the jetty or peninsula on which it will track out of the channel. The water here is 4 or 5 ft. deep. The important thing in making these crossings is to leave waterway enough so as not to increase velocity of current to the point where the loose material at the ends of the "island" will be washed out. Character of material available is sometimes quite a factor. In this case the material was ideal for the purpose, with a good percentage of coarse heavy gravel.

Delays and Interruptions.—Interruptions in the operation of dragline machines constitute an essential part of their cost of operation. Delays may be classified as major and minor.

Major delays include major repairs and overhauling of the machine, accidents with their resultant repair, and delays due to high water. All are more or less unavoidable in nature, but the extent of time consumed may be regulated in most instances. Even high-water delays can be reduced by so planning the work as to have the machines in locations not subject to such danger during the seasons when floods may reasonably be expected.

Minor delays include minor machine adjustments and repairs, changing cables, moving the machine, power delays (due both to circuit shut-offs and moving of transformers), delays incidental to car loadings, etc. Although the duration of separate minor delays is short, their total for a season's work is generally greater than the total of major delays. Moreover, the human equation enters into this class of delays to a large extent, thus offering a prolific field for the promotion of more efficient machine operation, and efforts should be concentrated on reduction of these delays.

On jobs of some size it is well worth while to install on the machines some type of automatic recorder which will give a graphic record of the periods during a working shift when the machines were in operation and when idle. The "Service Recorder" is a type commonly used in connection with motor-truck operations, but it can be readily adapted to use on dragline machines. The chart revolves by clockwork and the period of operation is recorded by a stylus attached to a pendulum so constructed as to oscillate when the machine is in motion. The recorder should be fastened to the side of the dragline cab, near the rear, there being the most definite vibration of the machine at that location. Figure 32 is a specimen chart of a day's run of a dragline. Such

records, besides being of value for reference and study, can be used in another way. By making the results known to the operators from week to week, a friendly rivalry between the several crews can be stimulated, and often the amount of output can be thus increased.

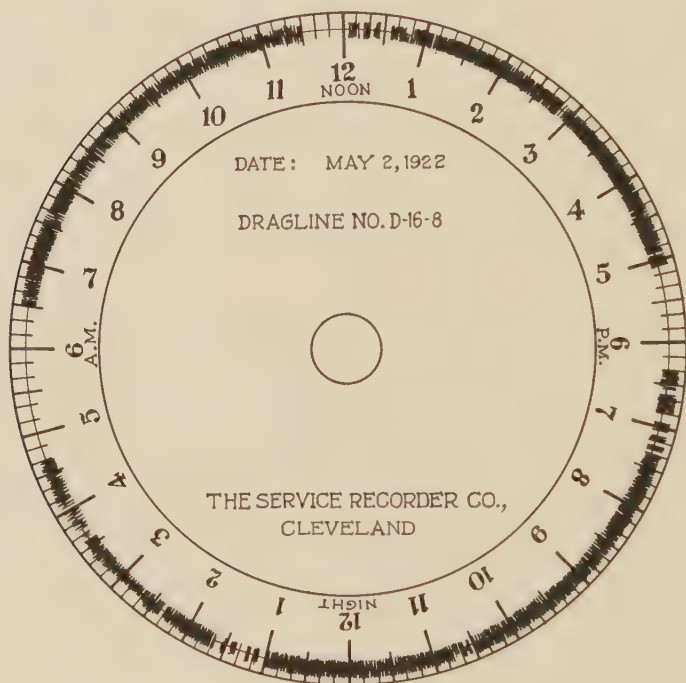


FIG. 32.—Service-recorder record.

The service recorder is a type commonly used in connection with motor-truck operations. It was adapted to use on dragline machines and gave a positive record, inaccessible to the operator until released, showing exactly the periods during the shift when the machine was in operation and when it was idle. For example, this card shows the morning shift starting at 6:30 a. m. with the work uninterrupted until the regular shut-down at 11:30. There was intermittent work from 12 until 12:40, and then continuous work until 5 o'clock with a slight interruption for a few minutes at 2:50, and so on for the rest of the day. All the interruptions indicated on the chart are fully explained in the dragline runners' report.

Where electric machines are used a voltmeter chart, such as is illustrated in Fig. 33, will furnish information regarding delays. This chart has the added advantage of showing each separate cycle of operation, thus making it possible to analyze the performance of the machine over long or short periods. Most

"time-of-swing" records are made over a short period, and very often are recorded only for work under favorable circumstances.

Analysis was made of the performance of an electric machine during an entire month. The total possible working time during this month was 500 hr., of which 431 hr. and 30 min. were spent in actual digging, the other time being spent in moving, waiting for cars, minor repairs, etc. The maximum number of swings per hour during this month was 82, an average of one swing in 44 sec., but for one day the highest number of swings was 1,332, or

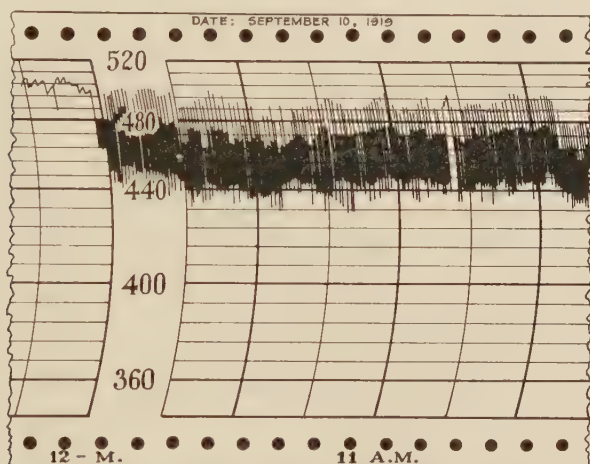


FIG. 33.—Voltmeter chart of dragline operation.

This instrument gives the same information as that described under Fig. 32. In this case there was only one electrically operated machine on the job and the voltmeter was placed in the office of the superintendent, giving him positive information during every hour of the day whenever the operation of the machine was interrupted from any cause. This portion of the chart covers only about 2 hr. running. Reading from right to left it shows uninterrupted work from about 10:15 until the regular shut-down at noon except for a few moments at about 10:50. This chart has the advantage of showing also each separate cycle of operation.

an average of one swing in 54 sec.; and for the whole month the number of swings was 25,543, or an average of one swing in 1 min. and 12 sec.

The maximum yardage for one day was 4,350, while the average for the month was 2,900 cu. yd. per day. These figures are given simply to emphasize the difference between maximum performance for a short time, and average performance over long periods.

Table IX gives the relation of possible operating time to actual operating time for a steam and an electric machine of the same size on the same job—a large borrow pit—for a season. Table X classifies dragline delays during a 3-month period. This classification is fairly representative of what may be expected on such machines, loading cars from a borrow pit in river gravel and sand.

TABLE IX.—DRAGLINE PERFORMANCE—ENGLEWOOD DAM SEASON OF 1920

	Total work- ing time, hours	Actual digging time, hours	Time lost, hours	Per- cent of delays	Num- ber cars	Cubic yards
Steam dragline						
April.....	490	466.75	23.25	4.7	5,666	48,000
May.....	500	491.42	8.58	1.7	8,396	71,000
June.....	520	499.67	20.33	4.0	9,142	78,000
July.....	520	479.50	40.50	7.8	9,909	84,000
August.....	520	463.17	56.83	10.9	9,270	79,000
September.....	500	455.33	44.67	8.9	8,948	76,000
October.....	400	356.91	43.09	10.8	6,759	57,000
November.....	470	401.91	68.09	14.5	7,035	60,000
December.....	340	320.33	19.67	5.8	5,452	46,000
Totals.....	4,260	3,934.99	325.01	7.6	70,577	599,000
Electric dragline						
April.....	460	438.67	21.33	4.6	6,325	54,000
May.....	500	476.41	23.59	4.7	8,578	73,000
June.....	520	488.60	31.40	6.1	9,016	77,000
July.....	520	425.75	94.25	18.1	8,085	69,000
August.....	520	484.60	35.40	6.8	8,904	76,000
September.....	500	454.00	46.00	9.2	8,547	72,000
October.....	390	359.25	30.75	7.9	5,700	48,000
November.....	480	446.60	33.40	6.9	7,798	66,000
December.....	340	332.41	7.59	2.2	6,188	52,000
Totals.....	4,230	3,906.29	323.71	7.7	69,141	587,000

TABLE X.—ANALYSIS OF DRAGLINE DELAYS—JULY TO SEPTEMBER, 1921

	July						August						September					
	Electric			Steam			Electric			Steam			Electric			Steam		
	Hours	Per cent	Hours	Hours	Per cent	Hours	Hours	Per cent	Hours	Hours	Per cent	Hours	Hours	Per cent	Hours	Hours	Per cent	Hours
Possible working time.....	485	100	485	100	86.7	540	100	87.5	540	100	86.7	540	100	81.7	500	100	83.9	500
Actual time digging.....	434.5	89.6	420.4	86.7	7.7	472.25	98.5	1.0	510.3	94.5	11.6	408.3	75.8	2.3	491.5	102.6	2.3	491.5
Electrical delays.....	3.75	0.8	.....	.....	.....	5.3	1.1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Mechanical delays.....	27.25	5.6	37.6	7.7	4.4	23.9	4.4	2.7	16.2	3.0	3.0	7.7	1.5	1.5	49.0	10.1	1.5	49.0
Waiting for cars.....	20.42	4.2	27.0	5.6	5.6	38.5	7.1	7.1	13.5	2.5	2.5	72.4	14.5	14.5	31.5	6.5	6.5	31.5
Total delays.....	51.5	10.6	64.6	13.3	13.3	67.7	12.5	12.5	29.7	5.5	5.5	91.7	18.3	18.3	80.5	16.1	16.1	80.5
Cubic yards, day shift.....	37,500		31,900			43,700			41,200			32,600			33,000			33,000
Cubic yards, night shift.....	34,200		29,000			41,300			36,800			29,700			29,000			29,000
Total yardage.....	71,700		60,900			85,000			78,000			62,300			62,000			62,000
Cubic yards per running hour.....	165		145			180			153			152			148			148

METHODS AND PERFORMANCE RECORDS

River-channel Excavation.—The principal types of excavating equipment in general use for river-channel improvement work are dredges of various types and dragline machines. Where the cuts are comparatively shallow, the streams not very deep and the material is of a gravelly nature, the dragline machine has several advantages over the dredges. Dredges require considerable depths of water for flotation, usually greater than required on ordinary channel improvement works, except in the largest streams. The dragline has greater flexibility and a much greater reach than the dredges. Of course, on the larger rivers, such as the Mississippi and Ohio, the dragline cannot be used. On such streams channel excavation must of necessity be a dredging operation.

In laying out the method of procedure on a channel improvement job consideration must be given to the nature of the material; its position in the channel; the location of the spoil banks and the location of proposed levees adjacent to the channel; and the means of transporting the excavated material to its final location.

When a dragline machine is used the nature of the material to be excavated matters little (unless considerable rock excavation is involved), so far as the method of procedure is concerned, except that in some cases the kind of material may be such that it will be necessary that the work be carried forward from the upstream end of the job in order to prevent the formation of bars. Gravel, sand, or clay can be handled by the dragline with equal facility. It is only necessary that the material have sufficient stability to support the machine as it moves along.

Considerable study should be given to the position of the material in the channel and the location of possible spoil banks or levees to be built from the excavated material. These factors are the principal determiners of the method of procedure. On jobs of some size several runs or cuts by the machine will be necessary to complete the movement of the material. In such cases procedure should be governed largely by the seasonal fluctuations of the river level. The work should be so arranged that as nearly as possible the higher cuts away from the river can be taken out during the high-water season, the work nearer the middle of the channel being done in dry weather. The entire

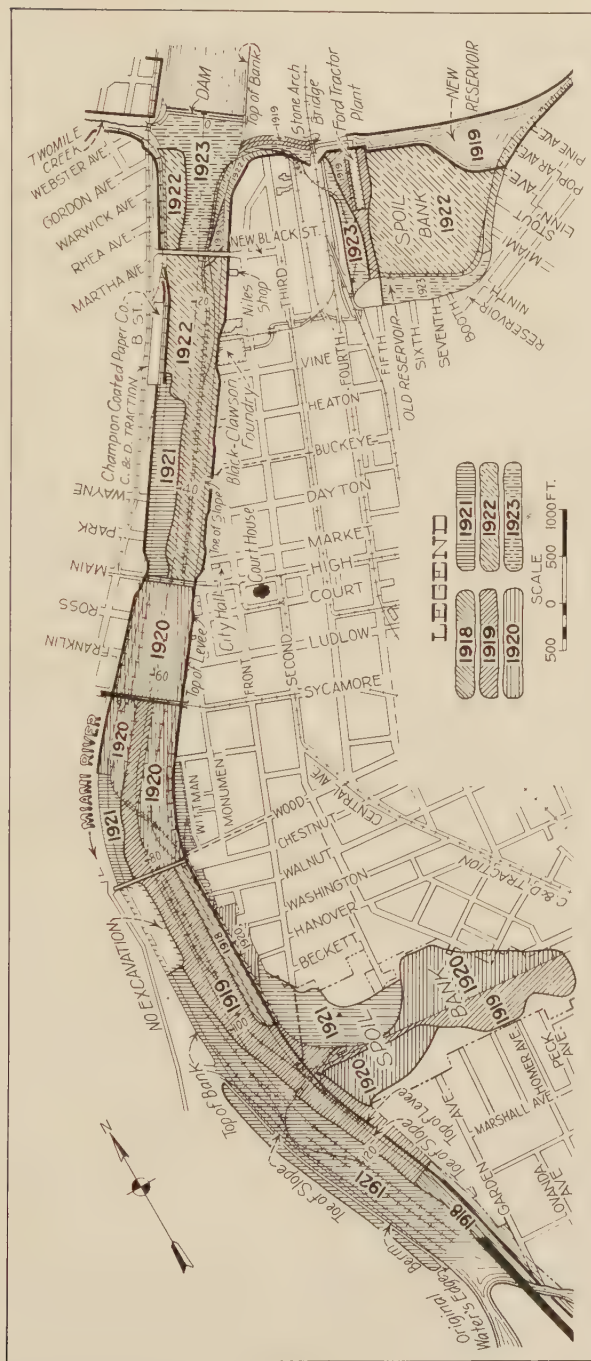


Fig. 34.—Channel excavation at Hamilton.

Showing channel excavation, spoil banks, etc., also the order of work by years.

construction layout should be arranged so that sudden rises of the river will do the minimum of damage and retard the progress of the work as little as possible. Attention to this matter will often save much time and considerable expense. In most localities it is possible to obtain through the Weather Bureau or other agencies warning of impending rises of the streams.

In general, it is of advantage to begin a river-channel improvement job at the downstream end, principally to lower the water level as the work proceeds. If a new channel or cut-off channel is being dug, it should of course be started at the lower end. Sometimes conditions favor or demand starting the work at the upstream end, however, and one advantage of this method is the prevention of formation of gravel deposits in the completed channel. On one job which was carried forward from the downstream end, high water in the spring following a construction season of considerable activity caused the deposit of about 150,000 cu. yd. of gravel in the completed channel.

The usual method of carrying out a channel improvement program by the use of the dragline excavator is illustrated in the following description of a large project at Hamilton, Ohio.

Here it was necessary to widen, deepen and straighten the old channel of the Miami River for a distance of about $2\frac{1}{2}$ miles. The improved channel varies in bottom width from 800 to 500 ft., and the slope of the channel is 0.08 per cent for the upper 6,000 ft. and 0.05 per cent for the remainder. There was a large surplus of excavation which had to be disposed of in two spoil bank areas, one at the extreme upper end of the job, the other near the lower end.

Practically all of the material to be excavated was heavy gravel. As only two spoil-bank areas were available, the average haul for excavated material was quite long—about 5,000 ft. for material hauled to the south spoil bank, and about 4,000 ft. for that sent to the north area. Figure 34 shows the general layout of work and the location of the spoil areas. Four draglines were used for excavating, with standard-gage railway equipment for transporting the material to the spoil banks. Most of the channel excavation was done by an electric machine mounted on skids and rollers. This machine was equipped with a 100-ft. boom and $3\frac{1}{2}$ - or $4\frac{1}{2}$ -yd. bucket.

The first work done was deepening the river channel around and through a large island at the lower end of the channel

improvement job. This was done to lower, as much as possible, the water level of the river above. The dragline started in about midway between the ends of this channel, worked downstream to the lower end, and completed the channel on the return trip. This channel was 45 ft. wide on the bottom, and the depth of cut was from 16 to 21 ft. through the main portion of the island. However, for a considerable distance the cut was shallow. The total yardage excavated from this channel was about 90,000 cu. yd.; the best month's run was 68,000 cu. yd., this in heavy cut.

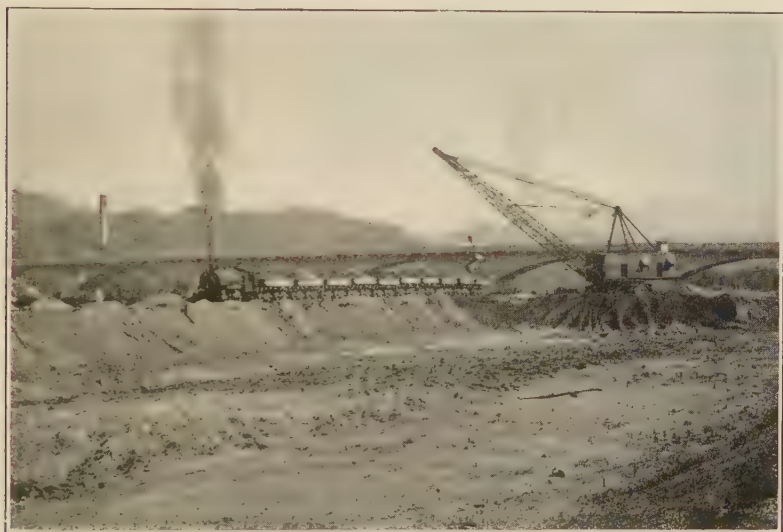


FIG. 35.—Large dragline on channel excavation.

The machine, equipped with 100-ft. boom and $2\frac{1}{2}$ -cu. yd. bucket, loaded into 12-cu. yd. dump cars, which were hauled in 10- to 13-car trains to the spoil bank.

About 5 months were spent in doing this job, but the result justified the work, for the water level in the channel above was lowered at least 6 ft.

While the dragline was digging along the east side of the river below the south spoil bank and casting directly into levee fill, construction of the tracks to the spoil bank was under way. A smaller steam dragline, caterpillar mounted, and equipped with a 60-ft. boom and $1\frac{1}{2}$ -yd. bucket was used to construct the track embankment. By the time the large machine had proceeded upstream to a point where it was necessary to dispose of excess material, the transportation equipment was ready to haul into the

spoil area. This area was about 3,000 ft. long and averaged 1,000 ft. in width, with its long axis practically at right angles to the river channel. Filling was started at the end farthest from the river on the left side of the main track, which extended about along the center line of the area. The average depth of fill in the spoil bank was about 10 ft. Throughout the job standard-gage 50-ton saddle-tank locomotives hauled trains of from 10 to 13 loaded 12-yd. air-dump cars to the spoil bank. The work was continued upstream along the east side of the main channel of the river by the large machine, assisted at times by the smaller one, to the upper limit of haul to the south spoil bank. This was about 6,000 ft. upstream from the spoil area (see Fig. 35).

When the excavation on the west side of the main channel was started, it was necessary to build two trestles across the river to enable the trains to reach the spoil bank. These were pile trestles; the decks of each were fastened together by old cable and tied to one bank of the river as a high water precaution. The upper trestle crossed the river diagonally and was low, the track being about 6 ft. above low water. The other trestle was built opposite the main track leading to the south spoil bank and crossed the channel approximately at right angles. It was necessary to build this trestle much higher than the upper one in order to secure a proper grade for hauling. Little trouble was had with the low trestle due to high water, though it was overtopped several times. The other trestle, being higher, collected a great deal of drift, and several bents were lost due to high water even before the deck was built.

The embankment for the necessary tracks laid during the excavation on the west side were built by a small steam dragline, caterpillar mounted, with a 32-ft. boom and $\frac{3}{4}$ -yd. bucket. This machine was used also to shift track on the spoil banks and for much miscellaneous work. In the larger cuts where practically all of the excavated material was hauled to spoil bank, track layouts were made so as to facilitate handling of trains with minimum delay to the dragline. Excavation on the west side was handled by working successive cuts up and down-stream from the center of the channel westward toward the bank. Tracks were so laid that two adjacent tracks were always available, one for loading and the other for accommodating empty trains. Cross-overs were laid where necessary so that empty

trains could pull over behind the ones being loaded; as soon as a loaded train pulled out, the empty one was on hand and there was no interruption to dragline operation. The upper trestle was removed by the dragline as it worked across the river south of the trestle. The lower trestle and approaches were removed after completion of all excavation which was to be hauled into the south spoil bank.

A total of 1,000,000 cu. yd. of material was moved into levees or spoil bank in three construction seasons, practically all of which was excavated by the large electric machine. During 5 months this machine moved a total of 378,000 cu. yd., an average of 75,600 cu. yd. per month. The best month's run for this period was 82,000 cu. yd. The average depth of cut on this section of the work was from 5 to 15 ft.

Work on the upper section of the channel improvement was started by the electric dragline soon after completion of the lower section. Prior to this time about 56,000 cu. yd. of channel excavation had been done by contract. This material was excavated by a steam shovel and was hauled to the spoil bank in 4-yd. dump cars by 16-ton dinkey locomotives operated on a 3-ft. gage track. The spoil bank for this material (and all spoil above the High Street bridge) was located at the upper end of the job and about 2,500 ft. east of the river. Some work had been done on the west side of the river by the small machine on caterpillars, the bulk of the material being cast into levee embankment, and the excess cast into the middle of the river to be picked up later by the electric machine. The small machine then proceeded to build the necessary track embankment on the east side of the river, leading to the upper spoil bank, so that everything would be ready for the larger machine when the major channel excavation was started. Track embankment was carried about 5 ft. above low water and 30 ft. wide on top for double track. It was so located that the center line of the east track was about 180 ft. from the top of the east bank. There were about 40,000 cu. yd. in the main portion of this track embankment.

The electric machine made practically all of the channel excavation on the upper section of the job in two seasons. There were heavy cuts along the east side running as much as 25 to 30 ft. deep in places. All of the material in this section was moved without requiring relocation of the tracks; the machine moved upstream between the tracks and the east bank, then

returned on the river side of the tracks, taking out the cut in the middle of the river. The track embankment was removed later by the same machine. It moved along the bottom east of the embankment, loaded the material on four- or five-car trains and tore up the track, placing rails and ties where they could be hauled away by teams. In a 6-month period 378,210 cu. yd. were excavated by the electric dragline, the average being 63,000 cu. yd. per month. The best month's run was 90,660 cu. yd.

High water during the spring, after the lower section (that part below High Street) had been completed, deposited considerable gravel in the completed channel below High Street, due to the decreased velocity when the gravel-laden water from the incompleted work above, reached the new channel. This contingency was considered when the work was started, but the advantage gained by lowering the water level of the river by working from the lower end was thought to outweigh this difficulty. Another reason for working upstream on this job was the necessity for coordinating the work of excavation with that of the removal of a number of factory buildings on the east bank of the river north of High Street bridge. These jobs required from 2 to 3 yr. and the excavation could not be undertaken in their vicinity until they were practically completed. The gravel deposit referred to amounted to about 150,000 cu. yd. It was removed by the electric machine, after completion of the heavy work above High Street. Two cuts were necessary, one following the deep portion of the channel and a second adjoining this on the east. Upon completion of this work the track embankment was dug out by the dragline, which moved along the bottom east of the embankment.

A cutoff channel joining a creek to the river above the main channel improvement was constructed by a small steam dragline, mounted on skids and rollers, and equipped with a 60-ft. boom and $1\frac{1}{2}$ -yd. bucket. The channel has a bottom width of 100 ft. and is 2,000 ft. long. The total excavation was 92,000 cu. yd., and all the material was wasted at the sides of the channel.

Total channel excavation made by the electric machine was 2,548,000 cu. yd.; of this amount 1,780,000 cu. yd. were classified as "pay excavation," the remainder being material excavated beyond payment lines and work necessary for moving the machine and track. The above figures are for material moved once. Some of this material was moved a second time in order to get it

into final position or loaded onto cars. Total "pay" channel excavation at Hamilton amounted to 2,142,000 cu. yd.; this figure does not include the 92,000 cu. yd. in the Fourmile Creek cutoff. Below are given the cost figures for the channel excavation by a large machine for a period of 5 months, when 378,000 cu. yd. were removed on the lower section of the job, and for a period of 7 months, when 378,210 cu. yd. were removed on the upper section. The figures include the cost of hauling, dumping, and spreading. The dragline was operated on two 10-hr. shifts per day. Wages varied somewhat, but during the periods referred to dragline operators were paid \$250 to \$278 per month, oilers 50 to 56 cts. per hour, locomotive runners 50 to 55 cts. per hour, brakemen 40 cts. per hour, and laborers 35 to 40 cts. per hour. The hourly rates are for an 8-hr. day. Workmen were paid for 11 hr. when working 10-hr. shifts.

TABULATION OF COSTS

A. Channel excavation on lower section (378,000 cu. yd.)		Unit cost	Per cent of total
Superintendence and overhead.....	\$ 5,119.38	\$0.013	3.1
Labor.....	87,673.54	0.233	55.5
Supplies.....	38,445.87	0.102	24.3
Power.....	5,073.40	0.013	3.1
Plant depreciation.....	21,847.60	0.059	14.0
Total.....	\$158,159.79	\$0.420	
B. Channel excavation on upper section (378,200 cu. yd.)			
Superintendence and overhead.....	\$ 9,985.22	\$0.026	5.0
Labor.....	103,531.66	0.274	53.0
Supplies.....	46,848.31	0.124	24.0
Power.....	7,191.08	0.019	3.7
Plant depreciation.....	27,383.05	0.074	14.3
Total.....	\$194,939.32	\$0.517	

The unit cost of the excavation on the cutoff job was 19 cts. per cubic yard. At the time this work was done dragline operators were paid \$250 per month; oilers, 46 cts. per hour; firemen, 46 cts. per hour, and laborers, 30 cts. per hour.

The final unit cost of excavating and disposing of all channel excavation at Hamilton, a total of 2,234,642 cu. yd., was \$0.643 per cu. yd., showing the effect of winter work, lean work, and long-time averages, as compared with the figures given in the preceding tabulations.

A channel-improvement job calling for somewhat different methods of disposing of the excavated material was that at Dayton, Ohio. The length of improved channel there was 6.1 miles and 2,146,000 cu. yd. of material were moved. The nature of material excavated was gravel similar to that at Hamilton, but the depth of cut on the Dayton job was much less than at Hamilton, averaging about 3.6 ft. On this job the excavation was carried forward from the upstream end, principally because it was desired to maintain flotation for scows in the upper section of the work.

The excavating equipment consisted of four machines. Two large electric draglines, operating with 125 to 135-ft. booms and $3\frac{1}{2}$ - to $4\frac{1}{2}$ -yd. buckets, and mounted on rollers and trucks, did all of the heaviest work. Another electric dragline, mounted on rollers, and equipped with a 100-ft. boom and $2\frac{1}{4}$ - to 4-yd. bucket, was used for unloading scows and work around the spoil banks and for digging a cutoff channel at the lower end of the job. For miscellaneous small jobs and work in places where the larger machines could not conveniently operate, a small steam dragline was used. This machine was caterpillar mounted and equipped with a 60-ft. boom and 1- to $1\frac{1}{2}$ -yd. bucket.

Figure 36 shows the general layout of channel excavation at Dayton. The work above Washington Street was quite different from that below this point, and the job naturally fell into two main sections. Practically all of the excavation above Washington Street was shallow, and a large amount of the material had to be transported to spoil banks. There were three of these areas, two near the mouth of Mad River and one at the mouth of Wolf Creek.

That section of the channel work through Dayton between the mouth of Wolf Creek and Mad River was of such character that ordinary dragline operations were not entirely practicable. There was no chance to place the excavated material into levees or waste banks even by moving several times. It had to be hauled away. A car and track proposition would have been very expensive and difficult to manage, and would have been subject to

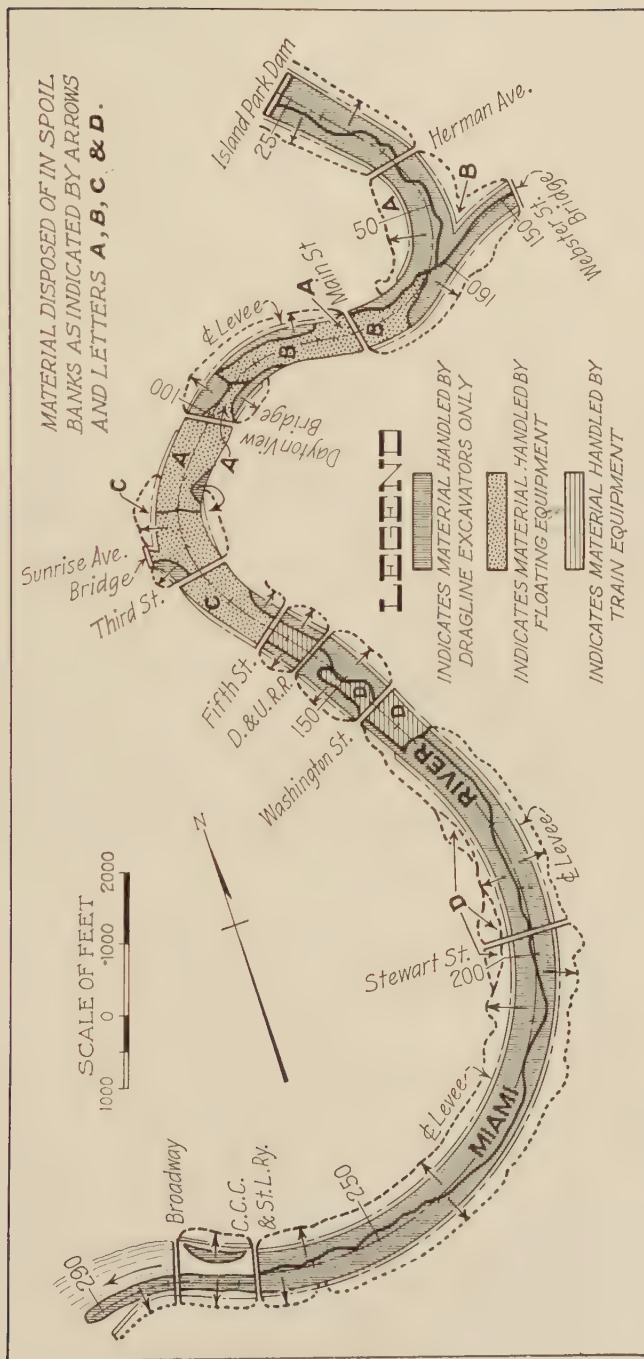


Fig. 36.—Channel excavation at Dayton.

Showing channel excavation and methods of handling, location of spoil banks, etc.

frequent damage from high water, because of the river-channel conditions along that section. Most of the material in question was below water level, and practically all of the work was shallow cutting. It was finally decided to mount a dragline machine on a spud scow, load the excavated material on to other scows, to be towed to available spoil banks and unloaded by another dragline standing on shore. Considering the inherent difficulties of the job, this worked out very well.

Figure 37 shows the "fleet," and the work under way. The dragline machine was an electric, equipped with a 100-ft. boom



FIG. 37.—Dragline dredge, scows, and tug boat, excavating river channel.

The scow at the left is being loaded by the floating dragline. The scow at the right is being swung into mooring position temporarily until the loading of the other one is completed. Another dragline machine on shore at the left end of the concrete bridge is unloading another scow and placing the material in the spoil bank. The tug boat and scows were built on the job.

and a 5-cu. yd. bucket. The scows and the tug boat were built at a temporary "shipyard" on the river bank at Dayton. The spud scow was 40 by 80 by 7 ft. with four 24- by 24-in. spuds, one at each corner. The dirt scows were 40 by 120 by 6 ft., decked over. Three of them were required. The tug boat was 20 by 70 by 3.5 ft., flat-boat, stern-wheel type, operated by steam. In order to get flotation at low water, it was necessary to build a low temporary dam just below the lower end of this section of work.

In mounting the dragline on its scow the trucks and subbase were dispensed with, so that the center of gravity of the outfit was lowered as much as possible. A plan was worked out for reversing the bucket, so that it would load by being pulled away from the machine. It was thought that that would avoid piling up loose material just in front of the scow. As a matter of fact, the regular method of loading the bucket, that is, by pulling it toward the machine, gave no trouble, and the scheme for reversing the bucket was never put into use.

An ordinary load for the deck-scows was 200 to 250 cu. yd. The maximum length of haul to the spoil bank was about 6,000 ft. with an average haul of about 3,000 ft. There were two bridges crossing the river along this section of the work which slowed up towing operations somewhat, especially during windy days and during periods of high water.

The loading of the scows was an ordinary dragline operation, slowed up of course by the fact that all excavation was shallow cutting, under water, and that the completed channel had to be reasonably close to the required lines and grades. The unloading, by machine on shore, was accomplished with a flat-bottomed bucket without teeth, taking off as much as possible of the load and throwing it directly into the spoil bank. Naturally some of the material was dragged off into the water during this process and that was picked up again and disposed of between trips. To finish the unloading a timber drag, hung from the bucket, was used to scrape off the scatterings. At first a low timber bulwark was built near the edge, along one side of the scow, to afford a solid face against which the bucket would work in unloading. It was found, however, that some material was always left along the sides of the bulwark, resulting in wasted space and causing the scow to list badly when empty. This added to the draft and made it harder to manipulate, so the bulwarks were removed. As a matter of fact, the unloading machine always had time to clean up, because navigation troubles and other delays when they occurred, affected the other units much more than it. By working upstream with the spud scow and letting the deck scow trail downstream, it was easy to manipulate the latter for loading, with one line. The tug would bring the empty down within reach of the dragline machine, which would shift the scow into exact position. At the unloading point the scow was held fast by lines from the shore.



FIG. 38.—Loading scows from the shore.

On some of the work a dragline machine working from the shore loaded the scows for transportation to the spoil banks, while the unloading was done by another machine as shown in the previous illustration.

About 350,000 cu. yd. of material were moved by this floating equipment in the manner just described, and the deck scows and tug boat were also used for transporting much other material which was loaded by a dragline working on the shore, as shown in Fig. 38. Field costs during a typical month show a unit cost for this work of 73 cts. per cubic yard and subdivided as follows:

	Cents per Cubic Yard
Loading scows.....	20
Transporting.....	26
Unloading.....	19
Distribution general items.....	08
Total field cost.....	73

to which about 3 cts. should be added for overhead and general expense. Plant charge, field engineering, and inspection are included, but no allowance for extra expense due to winter work and extraordinary delays.

At the time this work was being done common labor was paid 40 to 46 cts. per hour, dragline operators \$250 to \$280 per month and electric power cost about 1.9 cts. per kw.-hour put on the distribution lines. This was a piece of work that involved shallow cutting, much moving, long hauls, and was hard to do with any kind of equipment. The average output of the dragline on this work was 19,000 cu. yd. per month and the maximum, 55,400 cu. yd. per month, while on similar river channel work but where the machine was on land and could cut and waste, the same machine averaged 40,200 cu. yd. per month and had a maximum monthly output of 69,100 cu. yd.

Another combination of dragline machine and scow is shown in Fig. 39. This is a small machine on caterpillars, with a small spud scow, 30 by 69 by 6 ft., on which it was mounted for odds and ends of river work, or was transported up and down river for work ashore. This outfit did a great variety of work such as helping to lower or change pipe lines crossing the river; cleaning out under bridges or around bridge piers at points where the big machines could not reach conveniently; excavating for structures at sewer outlets; building temporary dam to obtain slack water for floating equipment; pile driving; excavating gravel for concrete; and many miscellaneous jobs for cleaning up. It was very convenient largely because of its mobility, as it could work either



FIG. 39.—Caterpillar dragline mounted on scow.

This combination was very useful for performing odds and ends of river work like cleaning out under bridges or around bridge piers, excavating for structures at sewer outlets, and other miscellaneous jobs where a larger machine was not available. The machine was thus easily transported up and down the river and could work either from the scow or from the shore as occasion demanded.

from the water side or from the shore side as occasion demanded. It could dock almost anywhere along the river by digging a pilot channel for itself in to the shore.

On a section of the work, extending from Fifth Street to a point about 800 ft. below Washington Street, 85,000 cu. yd. of the channel excavation was handled by a large electric machine and loaded on trains. The hauling equipment was similar to that used at Hamilton. The average monthly output on this part of the work was 24,500 cu. yd., and 48,800 cu. yd. were handled during the best month.

Channel excavation on the section of the work below Washington Street was handled by the two electric machines, except for

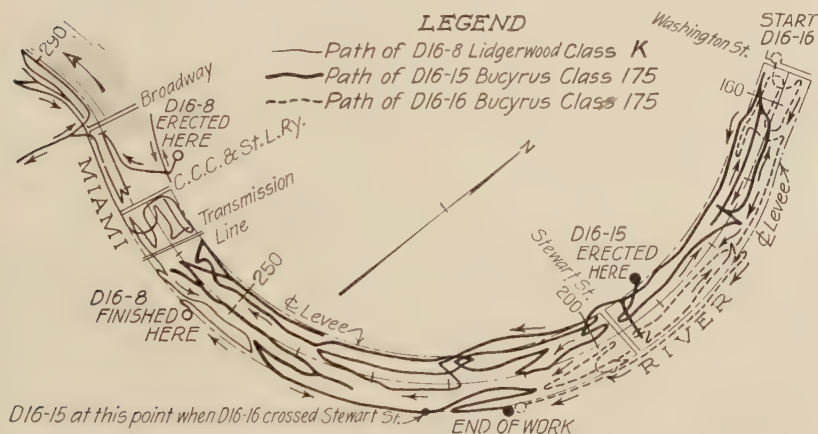


FIG. 40.—Dragline movements on Dayton Channel excavation.

This sketch shows the paths followed by three dragline machines in handling more than 1,000,000 cu. yd. of river-channel excavation.

a small portion at the lower end. Cuts were heavier on this section than above. The channel was divided into two portions longitudinally, the material being so divided as to provide the most economical balance of work for excavation and embankment, excavation going into embankment directly opposite to its original position as nearly as possible. No hauling of material was done on this section. One- and two-throw methods were used, and sometimes a third run was necessary. Figure 40 shows the paths traversed by the machines on this section. The total quantity excavated below Washington Street was 1,136,000 cu. yd.

At the lower end of the job a cutoff channel about 2,500 ft. long and 75 ft. wide on the bottom, was constructed by a steam machine. Total excavation for this channel amounted to 105,-000 cu. yd.

A small amount of channel excavation in Wolf Creek was handled by a small steam machine. Excess material was hauled to the spoil bank in 4-yd. side-dump, narrow-gage cars, hauled by steam or gasoline locomotives.

During a 16-month period of operation, the costs of excavation only by the two electric machines are shown below.

	Machine No. 15	Machine No. 16
Labor.....	\$37,171.79	\$37,314.58
Supplies.....	2,435.55	7,331.21
Minor repairs.....	6,613.39	4,137.07
Power.....	16,586.17	15,772.43
Cable.....	3,770.43	4,768.52
Miscellaneous.....	355.28	161.04
Depreciation.....	17,010.00	18,305.96
Total.....	\$83,942.61	\$87,790.81
Work done, cubic yards.....	981,989	641,510
Cost per cubic yard.....	\$0.085	\$0.137

The above costs contain all items chargeable to the work done and are based on the total gross yardages handled during the period, including second or third handling of material where necessary and estimated quantities of track fill. At the time the above work was done dragline operators were paid \$250 to \$280 per month; oilers, 50 to 56 cts. per hour; laborers, 40 to 46 cts. per hour; resident electricians, \$225 per month. Hourly rates are for 8 hr. work; payment for 11 hr. was made for 10 hr. work. The cost of electric power was about 1.9 cts. per kw.-hr. on the district's lines.

Below are given cost figures for channel excavation at Dayton on the section of the work below Washington Street for a typical period of operation. During this period two electric machines and one steam machine were operating. The quantity given is gross yardage—that is, for material handled more than once, each handling is included. Track fill is not included. The wage scale at the time this work was done was \$250 per month for dragline runners; 46 cts. per hour for oilers; 46 cts. per hour for firemen; 30 cts. per hour for laborers; \$200 per month for resident

electricians. All men on the hourly basis were given time and a half after 8 hr. The machines worked two 10-hr. shifts per day. All material moved was handled to the levees or spoil banks by the machines—no hauling was done. The work on this section was very well suited to dragline operation; cuts were fairly heavy and uniform and there were few obstructions, such as bridges, and no track laying.

COST OF CHANNEL EXCAVATION BELOW WASHINGTON STREET, DAYTON, FOR
TYPICAL PERIOD

		Unit cost	Per cent of total
Superintendence and overhead.....	\$ 7,613.96	\$0.010	7.4
Labor.....	45,661.37	0.062	45.9
Supplies.....	14,320.37	0.019	14.1
Power.....	11,424.20	0.015	11.1
Plant depreciation.....	21,205.71	0.029	21.5
Total.....	\$100,225.61	\$0.135	

The above for a total of 740,000 cu. yd. moved.

The unit cost of excavating and disposing of all channel excavation at Dayton, a total of 2,146,000 cu. yd., was \$0.637 per cubic yard.

Borrow-pit Excavation (Earth and Gravel).—Excavation from large borrow pits (where no rock is involved) or for gravel-plant operations can be handled by dragline machines, steam shovels, or dredges. Where the material must come from below water level the steam shovel cannot be used. The choice between dredges and dragline machines for operations of this kind depends largely on local conditions. The items of lower first cost, higher resale value, long reach and flexibility of operation all favor the dragline in most cases. Consideration must also be given to the transportation problem if the excavated material is to be used at any distance from the borrow pit. A suction dredge can pump direct from borrow pit to embankment, but if the pipe line has to be long, booster pumps must be used. There is also the element of wear and tear on long pipe lines.

In general, it may be said that the dragline and cars combination offers the most satisfactory and economical means of handling excavation from large borrow pits to embankments or waste

banks. This kind of work is required in connection with the construction of dams or other large earth works or in stripping operations for mining or other purposes.

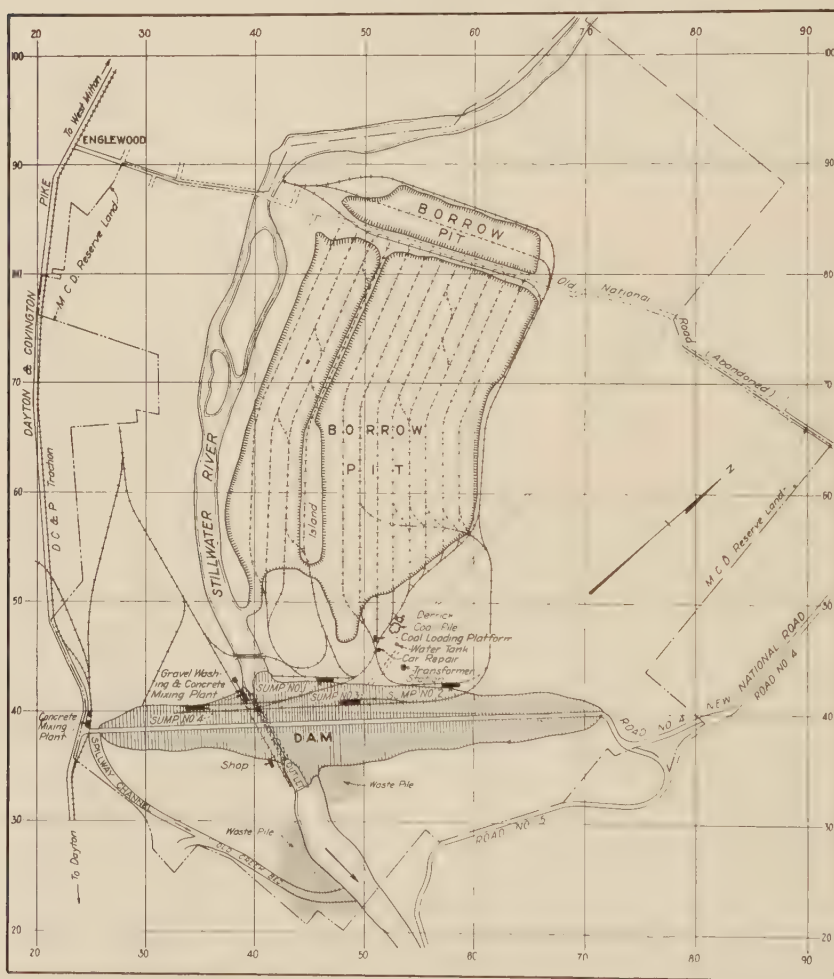


FIG. 41.—Borrow pit at Englewood dam.

This shows the layout of the borrow pit and track systems with reference to the dam itself. Nearly 3,500,000 cu. yd. of material were taken from this borrow pit for the hydraulic-fill embankment.

The size and number of machines to be used on a job depend on several factors, chief among which are the quantity of material to be excavated, depth of cut, distance to embankment opera-

tions, and the demand for the material at the embankment. For instance, if a dam is to be constructed by the hydraulic-fill process, it is probable that the speed of the operations will be determined by the ability of the pumping equipment to deliver material into embankment, and the excavating equipment may be chosen to deliver the amount necessary. Several dragline machines may be employed simultaneously on large operations. Figure 41 shows the layout of the borrow pit and track systems on a job where about 3,500,000 cu. yd. were excavated for hydraulic-fill embankment. The depth of cut varied from 15 to 20 ft., of which the lower 3 to 5 ft. was below water level. Three dragline machines were used; two large ones, equipped with 85-ft. boom and 4½-yd. buckets, handling most of the work. A smaller machine with 75-ft. boom and 1½-yd. bucket, was not used regularly for furnishing material to the dam, but was used for supplying concrete stock and various other purposes, and was called upon, if necessary, to supplement the output of the other machines. For transporting the material from the borrow pit to the dam, 12-yd. standard-gage air-dump cars and 40-ton standard-gage saddle-tank locomotives were used. Four yard cars were considered, but the larger cars are easier to load with a dragline machine as large as the ones required for this work, and the output is easier handled with the larger equipment.

The general method of operation in excavating this pit was for the two large draglines to travel up one cut and down the next, one ahead of the other, being spaced about half the length of the borrow pit apart. One would reach the middle of the cut where the other had started as the other reached the end, and both would move to a new cut at about the same time. The cuts ran north and south in the pit, progressing successively from west to east. The first cut was taken out near the river, the draglines loading on to a track at the east. Meanwhile a second track was laid 150 ft. farther east, ready for use upon the completion of the first cut. Thus tracks were taken up and relaid in succession along the pit 150 ft. apart as the succeeding cuts were made.

To maintain maximum output one important thing was to keep the draglines supplied with cars for loading. To accomplish this it was the rule that an empty train returning for reloading would proceed first to the southerly dragline, and if a train were already loading there, wait its turn; there would then be a train

loading at the other machine also. When the northerly dragline was completing the loading of next to the last car of its train, a whistle signal would be blown. At this signal the partially loaded train at the southerly dragline would move to the northerly machine, leaving its space for the next train. The time occupied in loading the last car was found to give time for the second train to come up, so that as soon as the loaded train at the northerly machine was ready to pull out, the train from the southerly machine was ready to slip into its place. This system worked out so well that it was seldom during the course of the work that



FIG. 42.—Dragline machine loading cars.

This is an electric machine with 85-ft. boom and $4\frac{1}{2}$ -yd. bucket. Under the conditions shown it was not unusual to load cars at the rate of a bucketful in 45 sec. Three bucketsful loaded a car.

either of the dragline machines was without cars to load. In case the train at the southerly dragline finished loading first, it would proceed to the dam by means of a cross-over. The empty trains on their return trip passed the coaling and watering stations, and took on fuel as required. For full service, six 5-car trains were used.

Figure 42 shows one of the dragline machines in action. The distance from the old track location along the outer edge of the cut, to the present loading track, is about 150 ft. The extreme reach from loading track to foot of slope at the outer edge of the cut is about 170 ft. To make this reach the machine has to

make nearly the full 180-deg. swing. The depth of this cut is about 16 ft., about 4 ft. of which is below water.

Spotting the bucket over the car, so as to dump quickly without spilling the material, turned out to be much less difficult than had been anticipated, although, of course, it required a skilful operator. Digging under these conditions, with part of the material below water, and making the full 180-deg. swing for the outside material, it was not at all uncommon to load cars at the rate of a bucketful in 45 sec. In fact, one operator loaded cars for a full 10-hr. shift at an average rate of 72 swings per hour.

The dragline machines worked two 10-hr. shifts per day. To illustrate the capacity of the machines under these conditions, and the amount of delay that may be expected on work of this sort, a reference to Table IX will show performance for one working season, April to December, inclusive. Out of a possible working time of 4,260 hr. one machine put in 3,935 hr. of actual digging time, the lost time amounting to only 7.6 per cent. The other machine with a possible working time of 4,230 hr. was actually digging during 3,906 hr., showing 7.7 per cent loss of time. During this period one machine loaded 70,550 cars—a total of 599,000 cu. yd.; while the other loaded 69,141 cars—a total of 587,000 cu. yd., measured in the dam in each case. Seventy thousand cubic yards per month for either machine was a fair month's work, and during 1 month one of the machines has a record of 84,000 cu. yd. The biggest month for the other machine was 77,000 cu. yd. The best record for one 10-hr. shift on this work was 2,329 cu. yd., or 274 cars. Table X gives an analysis of the causes of delays on each machine over a 3-month period.

In taking an average over a long period it was found that the capacity of a 12-yd. car as loaded under these conditions amounted to about $8\frac{1}{2}$ cu. yd. in the hydraulic-fill embankment.

On another job one electric dragline equipped with 100-ft. boom and $3\frac{1}{2}$ -yd. bucket averaged 50,000 cu. yd. of material per month, and during one month approximately 70,000 cu. yd. were taken out. Here the borrow pit was long and narrow, being about half a mile long and only from 200 to 450 ft. wide. The track system was so arranged that an empty train backed in as soon as a loaded train pulled out. Only two trains were used, each of five 12-yd. cars.

An electric machine equipped with 100-ft. boom and $4\frac{1}{2}$ -yd. bucket was used on another borrow-pit job in which the material was gravel and some overburden, and the performance record during one working season is given below.

TABLE XI.—DRAGLINE PERFORMANCE—HUFFMAN DAM, SEASON OF 1921

	Cubic yards excavated in month	Possible digging time includ- ing delays, hours	Cubic yards per hour includ- ing delays	Actual digging time, hours	Cubic yards per hour actual digging time
January.....	60,440	500.00	121	370.35	163
February.....	20,940	295.75	71	199.79	105
March.....	62,130	470.00	132	361.66	171
April.....	66,840	520.00	129	444.42	151
May.....	70,610	500.00	141	437.92	161
June.....	60,660	527.17	115	386.62	157
July.....	53,630	475.30	113	406.56	132
August.....	60,190	540.42	111	435.57	138
September.....	50,000	477.46	105	367.34	136
October.....	50,560	529.63	96	395.65	128
November.....	43,450	464.50	94	346.07	125
Total.....	599,450	5,300.23		4,151.95	
Season average.....			113		144

Two trains served this machine, and the successive cuts through the pit varied in width from 125 to 150 ft. This pit was about 1,600 ft. long and averaged 1,000 ft. in width. The biggest month's work was 70,600 cu. yd., while a good average month's work was about 60,000 cu. yd. The actual time lost during the full period was $21\frac{1}{2}$ per cent of the possible working time.

Following are representative cost figures for borrow-pit excavation on the first and last of the three jobs above described covering several million cubic yards of material. The "Supplies" item includes coal, and electric power, as well as miscellaneous supplies. These figures include full depreciation for plant, and all costs properly chargeable to the work. Wages for dragline operators at this time were \$250 to \$275 per month, firemen 56 cts. per hour, oilers 56 cts. per hour, laborers 40 cts. per hour, all men on an

hourly basis being given time and a half after 8 hours (11 hr. pay for 10 hr. work).

UNIT COSTS OF BORROW-PIT EXCAVATION

	Job 1		Job 2	
	Cost per cubic yard	Per cent	Cost per cubic yard	Per cent
Superintendence.....	\$0.005	4.9	\$0.005	4.7
Labor.....	0.044	43.1	0.039	36.8
Supplies.....	0.033	32.4	0.035	33.0
Plant depreciation.....	0.020	19.6	0.027	25.5
	\$0.102		\$0.106	

In the Palo Verde valley in California a long earth levee was built by a dragline. This levee was 34 miles long, and had a 12-ft. top, with 3 to 1 slope on the river side and 2 to 1 slope on the land side. All material came from a borrow pit along the line of the levee. The outer portions of the embankment were placed first; then the center was filled in with the wettest material from the borrow pit. This was done in order to secure a compact core which would have a minimum of settlement.

The work was done by four gasoline-powered draglines, caterpillar mounted, each with 55- to 75-ft. booms and 1½- to 3-yd. buckets. The machines operated on the berm between the borrow pit and the levee, and one throw of the material placed it. Each machine had a crew of four men.

The machines, when equipped with 3-yd. bucket, averaged 1,100 cu. yd. of excavation each per shift of 9 hr. The cost of placing this embankment was 20 cts. per cubic yard. It was estimated that it would cost from 45 to 50 cts. per cubic yard to do the job with teams and scrapers.

Rock Excavation.—Employment of the dragline excavator in rock excavation is a comparatively recent development in the use of this type of equipment. However it has been demonstrated on several large jobs that the dragline excavator can be used successfully and economically on rock work of certain kinds. On these jobs the rock was a shale and limestone mixture, stratified, and fairly hard. It was overlaid with earth or gravel.

The required excavations were deep and wide, and were subject to flooding from streams running near them. For work of this nature the choice of excavating equipment would be between the steam shovel and the dragline machine. The dragline machine was selected for the following reasons: It could work from the top of the cut, and therefore do the work without danger of interruptions from flooding; it would excavate the rock to the actual width required, since it could load the material at the higher level, whereas a steam shovel would be obliged to take out extra width to make room for cars and track at grade; it could complete the excavation to full width in one cut, thus permitting subsequent concrete work to start as soon as the excavation had gotten well under way, whereas a steam shovel would have to take out several cuts, to get the required width, and therefore would have to practically complete all the excavation before concrete work could begin.

The methods used and results attained on two similar jobs of the kind of rock excavation above referred to will be described in some detail. Both of these jobs were on the Miami Conservancy District flood protection project in Ohio. The excavation was necessary for the outlet structures of the Germantown and Englewood dams, these outlets consisting of twin concrete conduits with wide stilling pools at the downstream end.

The outlet excavation at Germantown consisted principally of a trench about 30 ft. wide and 550 ft. long, with an average depth of about 28 ft., the lower half or more of which was in rock. This rock was what is known as Cincinnati formation, and consists of layers of hard limestone from a fraction of an inch to several inches in thickness interstratified with hard clay or shale. The shale remains hard and firm, where protected from the action of the elements, but slacks rapidly on exposure. At the downstream end the excavation was widened out to about 100 ft., and also was carried about 10 ft. deeper into the rock, in order to accommodate the stilling pool. At the upstream end the excavation was also widened to take care of the bell-mouth inlet.

The conduits were located along the foot of the hill, some distance away from the river channel. The material overlying the rock consisted of clay and gravel, and varied in depth generally from 12 to 16 ft., although it was considerably more in places on the up-hill side. The proportion of rock in the excavation, according to final figures was about 40 per cent.

The work was started at the downstream end, after building a cofferdam to protect against flooding from the river. The material was handled by an electric dragline machine with 100-ft. boom and 2½-yd. bucket, working from the top of the cut and cleaning up the excavation ready for concrete, as it moved upstream. The earth overburden was thrown over into the dam section, where it was used later as a part of the embankment, being worked into place by sluicing where necessary.

As soon as a 40- or 50-ft. stretch of rock had been laid bare, steam tripod drills were set up and the rock was drilled to within a few inches of the bottom grade. Generally speaking, the holes were drilled on about 5-ft. spacing, and were loaded with about a 10-lb. charge of 40 per cent dynamite. The drilling and shooting was usually done by the night shift, so that the dragline machine had the material to work on during the day shift. Special care was taken to avoid overbreakage, as every yard taken out beyond neat lines meant also an extra yard of concrete. This was very difficult, however, as the rock broke out so irregularly, and the only way to avoid excessive overbreakage was to keep the drill holes well within neat lines. This resulted necessarily in a large amount of trimming, which was taken up as a separate operation, but followed closely on the heels of the rough excavation, so that the material could still be handled by the dragline machine. This trimming was done with jap drills, picks, and bars, removing all material that had been loosened by the shooting or other operations.

The rock excavation was loaded into 12-yd. standard gage dump cars and hauled to the spoil bank about half a mile away. The trains were made up of four or five cars each, and were hauled by 40-ton saddle-tank standard-gage locomotives. As soon as a sufficient amount of excavation had been completed, the concrete work was started, thus permitting the two jobs to proceed simultaneously.

Very little trouble was encountered on account of water. One 4-in. pump, operated at infrequent intervals, was sufficient to take care of all seepage. This was due largely to the care with which the cofferdam was built.

A fair month's work was from 9,000 to 12,000 cu. yd., while the best month showed an output of over 16,000 cu. yd., the dragging working one 10-hr. shift per day. This was difficult work for any type of equipment, as is indicated by a glance at Fig. 43.

The long, deep, and comparatively narrow trench, and the large amount of trimming as compared with the total excavation, meant slow progress at best. The equipment and methods adopted seemed to be well suited to the job.

At Englewood the job was very similar to the one at Germantown. The conduit trench was somewhat longer, being about 700 ft. long at Englewood, and the earth overburden was con-



FIG. 43.—Rock excavation for outlet conduits at Englewood dam.

This illustrates a narrow trench which it was necessary to dig for the outlet conduits at Englewood and Germantown. The dragline machine could dig close to neat lines and clean up the trench as it moved along. The concrete work could start as soon as the excavation was well under way.

siderably less, averaging not more than 2 ft. The top 6 to 10 ft. of Cincinnati, however, was soft enough so that it could be excavated by the dragline machine without shooting. Therefore the same general method of procedure was employed as at Germantown; *i.e.*, to remove the overburden and softer material on top of the hard rock, leaving a bench of rock to be drilled and shot, usually by the night shift. The excavation, including the

trimming, was completed as the dragline moved on, except that during a part of the time the trimming was cleaned up by a locomotive crane, which was available on part time in connection with other work. The final classification of material at Englewood showed the proportion of rock to be about 75 per cent.

The excavating machine here was a steam dragline with an 85-ft. boom and a 5-yd. bucket. All of the material, including



FIG. 44.—Rock excavation for stilling pool at Germantown dam.

This shows the pit where the excavation was widened out to make room for the stilling pool. Even in the widest of these excavations the dragline machine could complete full width as it moved along so that concreting could follow without delay.

the overburden, was loaded into 12-yd. standard-gage dump cars, and hauled away in four- or five-car trains by means of 40-ton saddle-tank standard-gage locomotives. The distance to the spoil banks was less than at Germantown, averaging not more than a quarter of a mile. The progress of work was about the same as at Germantown, that is about 12,000 cu. yd. for an average month, with a maximum running somewhat over 16,000 cu.

yd. per month. Figure 44 is another view of this class of excavation, where the trench is widened out to make room for the stilling pool.

Below are given cost records for this excavation. These figures include the cost of trimming. At Germantown 98,000 cu. yd., consisting of about 60 per cent earth and 40 per cent rock, were moved at a unit cost of \$1.29 per cubic yard. At Englewood 67,000 cu. yd., of which about 75 per cent was rock, were moved for \$1.60 per cu. yd. Most of the difference was in the labor item, and is accounted for by the higher percentage of rock in the material handled.

These figures include general superintendence, full plant depreciation, and all costs properly chargeable to the work. The cost of headquarters office at Dayton was carried as a general expense item and was not distributed. This work was done at a time when labor was being paid 35 to 40 cts. per hour, dragline operators \$175 per month, blacksmiths 62½ cts. per hour, locomotive runners 50 cts. per hour, and drill runners 50 cts. per hour. All men on an hourly basis were given 11 hr. pay for 10 hr. of work. (10 hr. shifts with time and a half after 8 hr.)

COST OF EXCAVATION FOR OUTLET WORKS AT GERMANTOWN AND ENGLEWOOD DAMS

Germantown, 98,000 cu. yd. (60 per cent earth, 40 per cent rock)		Unit cost per cubic yard	Per cent of total
Superintendence and overhead.....	\$ 6,690.48	\$0.068	5.3
Labor.....	63,265.16	0.646	50.0
Supplies.....	34,973.33	0.357	27.7
Plant depreciation.....	21,418.25	0.219	17.0
Total.....	\$126,347.22	\$1.290	
Englewood, 67,000 cu. yd. (25 per cent earth, 75 per cent rock)			
Superintendence and overhead.....	\$ 5,254.80	\$0.078	4.9
Labor.....	58,563.86	0.875	54.5
Supplies.....	26,240.35	0.391	24.4
Plant depreciation.....	17,409.15	0.26	16.2
Total.....	\$107,468.16	\$1.604	

At two other dams, Taylorsville and Huffman, the outlet conduits were of a different type, being combined with the spillway structure. The cut for this structure at Taylorsville amounted to about 710,000 cu. yd., of which 500,000 cu. yd. was earth. The remainder, which was in Cincinnati rock, contained a large percentage of hard clay and shale. The earth overburden was handled by sluicing methods as no equipment for handling this material could compete with hydraulic giants under the conditions. For the rock excavation, however, the choice was not so simple. The first thought was for steam shovels and cars, but that involved some serious difficulties. The deepest part of the excavation was to be 40 ft. below low-water level in the river. The excavation for the structure foundation alone covered an area approximately 600 ft. long, and from 150 to 260 ft. wide. The pit would have to be protected from flooding by an ordinary seasonal flood, which meant building up dikes and cofferdams to elevations at least 12 to 15 ft. higher than ordinary low water, so the bottom of the pit would be 50 to 55 ft. below the top of the cofferdams. For steam-shovel work under such conditions the tracks would have to be brought out over the top of these protective works, which meant either a long runway out of the pit, involving additional excavation and much additional protective work for the runways themselves, or exceptionally steep grades to get the tracks out of the pit without making the runways too long. Moreover, the excavation for this structure was 260 ft. wide at the downstream end, and many runs would be required with a steam shovel to complete the excavation, and under those conditions none of the concrete work could be started until practically all the excavation had been taken out.

† A dragline excavator could take out this material, working from the top of the rock, and loading cars at that elevation instead of in the bottom of the pit. This would do away with the difficult problems of track grades and additional protective works. It also minimized the danger of delays from flooding. A dragline machine could start at one end and complete the excavation to grade and for the full width of the cut as it went, thus permitting the concrete work to begin as soon as the excavation had gotten a reasonably good start. While there was little doubt that a steam shovel would actually load this material into cars faster than a dragline machine could do it, it was

believed that taking the work as a whole, the dragline outfit would handle it more cheaply than the other. The final selection therefore, was a dragline machine, truck mounted, with 100-ft. boom and 3-yd. bucket. Dump cars of 12-yd. capacity and 40-ton standard-gage dinkeys were provided for hauling away the excavated material. A spreader car was used on the spoil banks.

The work started at the downstream end and was completed to full width and depth as the excavating equipment moved on upstream. First, the rock was drilled by electric well drills, the holes being about $4\frac{1}{2}$ in. in diameter, spaced about 10 ft. apart, both ways; 50 ft. of hole per 10-hr. shift was considered a good day's work. The first holes were loaded with about $1\frac{1}{2}$ lb. of 40 per cent dynamite per cubic yard of rock to be lifted, but after a start had been made and the work shaped up with a vertical face, the amount of explosive per cubic yard was reduced to about $\frac{1}{2}$ lb. The average for the whole job was 0.6 lb. per cubic yard.

For this excavation an electric dragline machine was used, with 100-ft. boom and $3\frac{1}{2}$ -yd. bucket. The material was loaded into 12-yd. standard-gage dump cars and hauled away in four or five-car trains by 40-ton saddle-tank standard-gage locomotives. The distance to the spoil banks was about 1,000 ft.

This excavation was made so wide and so deep, especially at the downstream end, that it was impracticable for the dragline to reach all the way across the cut from one position. It therefore, was turned so that it moved back and forth across the cut at right angles to the center line of the excavation, or parallel to the face of the cut. This machine was mounted on trucks, and the movement upstream was accomplished by curving the track upstream slightly each time across the cut, and straightening up at the end so as to reverse the curve going back. The working face was wide enough so that the drills could be working on one side while the dragline was cleaning up on the other. After the work was well opened up it was found that shooting off the whole face at once (a depth of 50 to 60 ft.) threw the top material so far out that it was difficult for the dragline machine to reach it. To avoid this, and to better break up the top layers, it was decided to drill and shoot in two lifts. Two rows of holes were drilled, 25 to 30 ft. deep. These were shot and the material cleaned up with the dragline. Then the drills were picked up by

the dragline machine and set down on this bench, from which the bottom material was drilled and shot; but before this bottom material was cleaned up, two more rows of holes were drilled and shot down from the top. This method was much more satisfactory than the original one of shooting off the whole vertical face at one time. Figure 45 is a view of this pit and some of the equipment used.

Some of this material near the bottom of the cut was so hard and firm that it broke up in chunks from 3 to 4 ft. in thickness.



FIG. 45.—Rock excavation at Taylorsville dam.

The rock excavation at this point was over 200 ft. wide and more than 60 ft. deep. Nearly 200,000 cu. yd. of rock were moved by the dragline, loaded into cars and hauled away. This view shows the wagon drills drilling for the second lift.

There were two or more well-defined strata where this occurred, and some of the material had to be block holed and broken up in the pit before it could be handled by the dragline. The material in these hard strata was no different than the rest, except that the layers of limestone and shale were so firmly held together that it had to be handled in the pit just as if it were a layer of solid rock.

In the drilling and shooting care was taken not to get any of the holes within 3 to 5 ft. of the neat lines on the sides, nor within 2 ft. of the finished grade at the bottom. Otherwise, there would have been danger of shattering or loosening the rock outside

the lines. This meant, of course, that the trimming was much more of a job than it had been at Germantown or Englewood; that is to say, it was heavier work, and much more material had to be moved. This trimming was handled, however, in practically the same way as at the other places; *i.e.*, by the use of jap drills, picks, and bars, and it was possible always to keep close up with the rough excavation so that most of the material could be handled by the dragline. Some difficulty was experienced in keeping above grade of the bottom excavation, because the constant dragging of the bucket over the bottom tended to continually loosen up the material. This was especially true at changes in grade where the bucket had to be dragged up an incline. At such places there was always a tendency for the bucket teeth to catch under a limestone layer and tear it loose. In this kind of rock it was much easier to hold to the lines when digging down an incline than when digging up the same grade.

An average month's work in this rock was about 15,000 cu. yd., and the best month shows an output of over 22,000 cu. yd. The work was carried on by two 10-hr. shifts per day, and because of the width of the cut, and the nature of the work, the drilling and blasting did not interfere to any great extent with the continuous operation of the dragline machine.

This was a rather unusual job for a dragline excavator, both because of the character of material handled, and because of the great depth of cut, which at one place was 63 ft. below where the machine stood. It was slow work at best. The wear on the drag cable was very severe and required careful watching. Frequent replacement of cable was necessary. The cost of cable alone ran as high as 3 cts. per cubic yard. The wear and tear on the bucket was also a considerable item of expense. But the great advantage of having the equipment up on top of the cut, out of the way of floods and water troubles, and with easy grades to the waste banks, justified the use of the dragline outfit. It is doubtful if any other equipment could have handled the work as satisfactorily.

The job at Huffman was very similar to the one just described, except that the dimensions and the quantities were not quite as large. This cut also took the form of a bench into the bluff along the edge of the river. The hillside slope was not steep, as at Taylorsville. The width of the cut varied from about 120 to 210 ft., and its total length was about 1,400 ft. including the

inlet and outlet channels to the old river bed. The material was very similar to that at Taylorsville, with some of the limestone layers as much as 15 in. in thickness. The total excavation amounted to about 175,000 cu. yd., of which about 80 per cent was classified as rock.

The overburden and soft rock at Huffman had an average depth of about 10 ft. This could have been removed without blasting, but the starting of the work here was dependent on the relocation of a railroad, which ran about along the center line of the location for the outlet structure. While a temporary relocation of this railroad was being made, the drilling was started on one side of the old railroad cut. The first lift was drilled to a depth of about 20 ft., which included the soft rock and the overburden, so that just as soon as the traffic had been turned from the old line of the railroad these holes were loaded and shot and actual excavation for the outlet structure was begun.

The excavating equipment used here was an electric dragline machine with 100-ft. boom and $31\frac{1}{2}$ -yd. bucket. The material was loaded into 12-yd. standard-gage dump cars, and hauled away by means of 40-ton standard-gage saddle-tank locomotives, as at the other dams. All of this waste material was used in the embankment for the permanent railroad relocation. The average haul to this embankment was about half a mile.

The economical procedure at Huffman was to remove the material in two lifts, taking first that which had been drilled previous to the railroad relocation, and on the uphill side of the old railroad cut. The machine started at the upstream end of the cut and the abandoned railroad line was used as a loading track. As soon as that lift had been completed the machine tracked back, at the same time cleaning up on the other side of the railroad cut all material that could be removed without blasting. This brought the machine back to the upstream end of the work, ready to start on the straight rock excavation.

In drilling for the second lift, holes about 18 ft. deep were sufficient for the portion of the excavation above the stilling pool. Most of the drilling was done with well drills similar to those used at Taylorsville, except that they were operated by steam, but at Huffman some drilling was done with a wagon drill. The wagon drill made much faster progress on actual drilling than did the well drill, but it was so much heavier and so much harder to move over the rough, irregular ground, that the actual

cost of drilling by the two types of equipment turned out to be practically the same; *i.e.*, about 31 cts. per foot. A fair day's work for the well drill was about 45 ft. of holes per shift, while the wagon drill actually made one record of 240 ft. of holes in one 10-hr. shift. This, of course, was in a place where very little moving was required, and conditions for moving were favorable.

In shooting the holes at Huffman it was found advantageous to use a small springing charge before the final loading of the hole. Springing the holes, however, had to be done very carefully, because if an overcharge was used it tended to break off pieces of the limestone layers and plug the hole. The holes were put down on about 10-ft. centers, and it was the practice to load about 20 to 25 of these holes and shoot them simultaneously. The amount of explosives used on this work was about $\frac{1}{2}$ lb. per cubic yard of material moved. The cost of drilling and blasting was $26\frac{1}{2}$ cts. per cubic yard.

When the deeper section of excavation was reached, another lift of holes was necessary to reach bottom grade. The cut was wide enough here, however, so that drilling and blasting could proceed at one side of the cut while the excavation was being made on the other; thus the entire cut was completed as the dragline passed through, as was done on the other jobs.

General excavation methods, and the trimming, were handled at Huffman in about the same way as at Taylorsville, except as has been noted. The fact that the Huffman excavation proceeded downstream, meant that the machine was excavating down the incline into the stilling pool instead of against the grade as at Taylorsville. This made it much easier to avoid tearing up the material from below grade, and emphasized what has already been mentioned, that in stratified material of this kind it is much easier, with a dragline machine, to keep close to the lines when excavating down an incline, than when going in the other direction.

In spite of the fact that a cofferdam was required all along the river side of the excavation, there was very little seepage into the pit except at high stages of the river, when a 4-in. and a 6-in. pump were required to keep the pit dry.

A rather unusual record was made at Huffman during the progress of this excavation, when the dragline machine took out a total of 25,000 cu. yd. of material while standing on the same

spot. This was at a point near the downstream end of the stilling-pool excavation where the bottom grade was nearly 60 ft. below the machine, and where the width of the cut was something over 210 ft. Figure 29, (p. 78) shows this interesting feature of that work.

A good month's work at Huffman was about 20,000 cu. yd., and on two different months this ran up to nearly 25,000 cu. yd. per month. It happened that during both the months when these higher records were made the material handled was more than 90 per cent rock. The work was carried on in two 10-hr. shifts per day.

Wear and tear on the dragline buckets has been mentioned as a considerable item of cost in connection with work of this character. A record was kept at Huffman which showed that the average cost of bucket repairs on this heavy excavation amounted to $1\frac{1}{2}$ cts. per cubic yard.

Below are given cost figures for the excavation at Taylorsville and Huffman, including the cost of trimming. At Taylorsville 178,000 cu. yd. of rock were moved, at an average cost of \$1.72 per cubic yard. At Huffman 173,000 cu. yd., of which 80 per cent was rock, were moved at an average cost of \$1.56 per cubic yard. These figures are made up on the same basis as those given earlier in this chapter for the work at Germantown and Englewood. They include general superintendence, full plant depreciation, and all field costs. The wage scale was the same as that given for the other jobs; *i.e.*, labor 35 to 40 cts. per hour, dragline runners \$175 per month, locomotive runners 50 cts. per hour, drill runners 40 cts. per hour, blacksmiths 60 cts. per hour, all men on an hourly basis being given time and a half after 8 hr., or 11 hr. pay for 10 hr. work.

COST OF EXCAVATION FOR OUTLET WORKS AT TAYLORSVILLE AND HUFFMAN

		Unit cost, per cubic yard	Per cent of total
Taylorsville, 177,800 cu. yd., all rock			
Superintendence and overhead.....	\$ 12,937.72	\$0.073	4.2
Labor.....	152,899.12	.859	50.0
Supplies.....	103,622.05	.583	33.9
Plant depreciation.....	36,333.61	.205	11.9
Total.....	\$305,792.50	\$1.72	
Huffman, 173,000 cu. yd. (20 per cent earth, 80 per cent rock)			
Superintendence and overhead.....	\$ 11,677.15	\$0.067	4.3
Labor.....	151,583.91	.876	56.1
Supplies.....	81,471.51	.470	30.2
Plant depreciation.....	25,341.55	.147	9.4
Total.....	\$270,074.12	\$1.56	

Dragline and Cableway.—The dragline machine has been used successfully for excavation in a deep gorge on one of the Reclamation Service projects. This was in connection with the construction of the Arrowrock dam in Idaho. A concrete dam 350 ft. high was to be constructed across a narrow canyon in the river. The depth below the river bed to bed rock was from 60 to 80 ft. and the overlying material, mostly sand and gravel, had to be removed. As this material was suitable for concrete aggregate, a method for handling it was worked out so that it could be placed convenient to later concreting operations. Two cableways were erected across the canyon and a dragline was set up in the river bed between them. This machine had a 70-ft. boom and 2-cu. yd. bucket and was mounted on skids and rollers. It excavated all the material in the river bed, loading into skips which were lifted and conveyed by the cableways to a large hopper on one side of the river under which was the screening and crushing plant. A row of skips was placed under each of the cableways, and they were loaded by the dragline first on one side and then on the other so that there was always a loaded skip ready to be picked up by the cableways. The skips were lifted from 275 to 350 ft. About 113,000 cu. yd. of material were

handled in this manner at a cost of \$1.11 per cubic yard, distributed as follows:

		Cents per Cubic Yard
Dragline:		
Labor.....	\$9,411.95	
Fuel.....	2,357.40	
Supplies.....	3,092.26	
Repairs.....	1,801.81	
Depreciation.....	2,025.26	
Preparatory expense.....	1,012.63	
	\$ 19,701.31	17.4
Derricks.....	10,631.90	9.4
Labor hooking skips, etc.....	42,752.88	37.8
Operating cableways.....	41,740.19	37.9
General expense.....	10,158.62	9.0
Total.....	\$124,984.90	\$1.11

The machine worked in two 8-hr. shifts, a third shift doing miscellaneous cleaning up and repair jobs. Coal cost \$7.40 per ton. At the time the work was done laborers were paid \$2.40 to \$2.50 per day (8 hr.); dragline runners and cable way engineers, \$4 to \$5; firemen, \$3; swingmen, \$3.50; and foremen \$125 to \$165 per month.

MISCELLANEOUS DRAGLINE OPERATIONS

Lowering Pipe-line Crossings.—Dragline machines have been used to good advantage for lowering water, sewer, and gas lines across river channels which were being improved. Of course, it would not pay, ordinarily, to set up a dragline machine for small jobs of this kind, but on channel excavation jobs where draglines are used they can be employed for such work. Procedure on one such job was as follows:

Having located a pipe line, a trench was dug as close as possible on each side of it with a dragline bucket, and the material excavated was used for a cofferdam around the section to be lowered, the track fill upon which the dragline traveled being utilized as one side of the cofferdam. When it was necessary to lower the pipe the whole width of the river, the work was usually divided into two sections, of approximately equal lengths, so as not to obstruct the flow of the river to too great an extent. The narrowest trench that could be excavated by the dragline bucket was

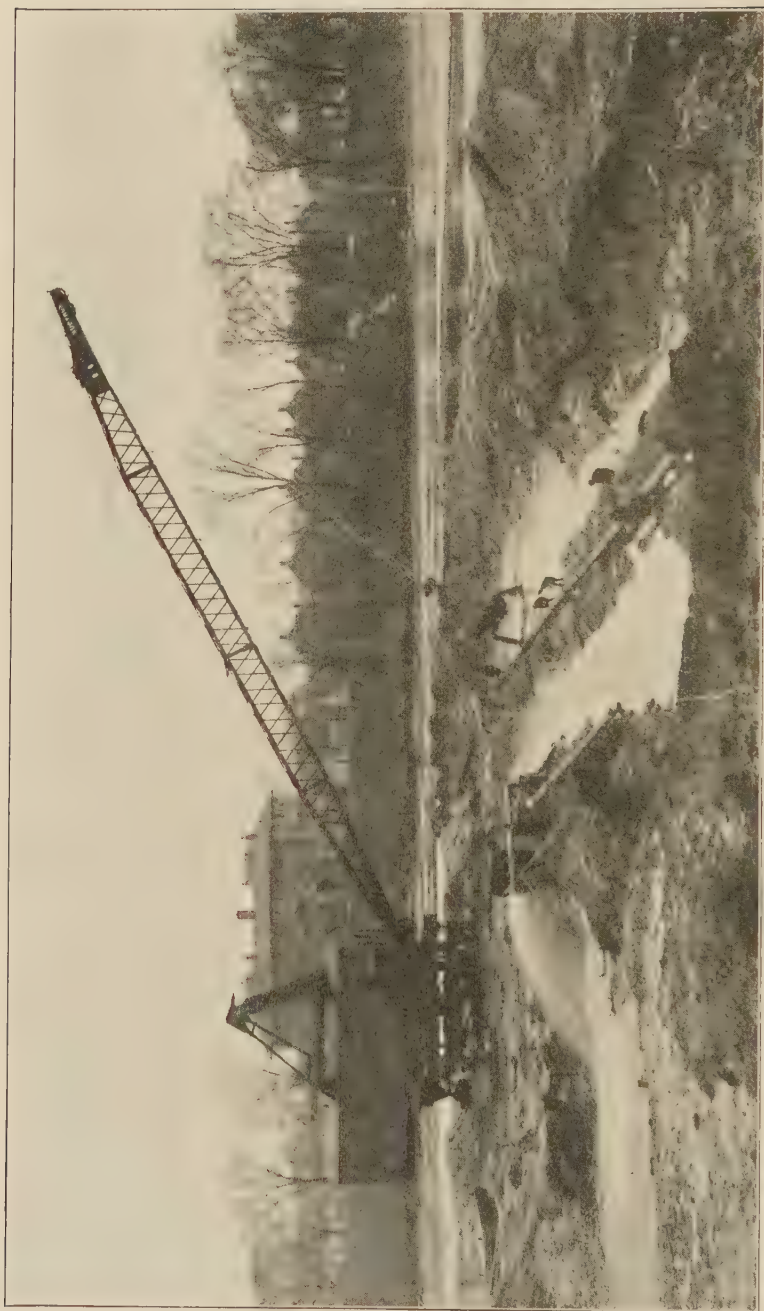


Fig. 46.—Lowering a water pipe across the Miami River.

This pipe was maintained in operation during the whole time that it was being lowered to its new position. The dragline machine performed the rough excavation, and the actual lowering was done by hand in a minimum amount of time.

considerably wider than was required for the actual pipe work, but the extra width thus made available was convenient for the necessary hand work in completing the excavation around the pipe or in handling the pipe itself. Unwatering pumps, pipes, etc., were easily moved from place to place by the dragline machine. Sumps were readily excavated to any required depth, and altogether the procedure was very satisfactory. More material was excavated than would have been the case if sheeted trenches had been dug or if open trenches had been dug by hand, but the advantage gained in doing away with the sheeting and having ready at all times a powerful and positive excavator, much more than offset the disadvantage of handling the extra material. Notwithstanding the large quantities, the unit cost was so much less than could have been achieved by any other means, that a considerable saving was made on the job as a whole.

Figure 46 shows a large dragline machine lowering a 12-in. water main. After the trenches on either side were excavated, men with shovels carefully lowered the pipe by digging the material from beneath it. In this case the pipe was continued in service during the whole process of lowering, although the pressure was somewhat reduced temporarily, as a matter of precaution.

Building Bridge Piers.—On a large seven-span reinforced concrete bridge job a steam dragline, mounted on caterpillars, and equipped with a 75-ft. boom and a $1\frac{1}{2}$ -yd. bucket, was used to excavate for the piers and abutments, and to drive piling for the pier foundations. Notwithstanding the fact that the excavation for the piers had to be carried down 15 ft. or more below the river bed, the work was accomplished successfully in open cut by the dragline machine, and a considerable saving in time and cost was effected. In one case it was possible to excavate for two piers within the same cofferdam.

The excavated material was thrown up around the excavation to form a cofferdam, the machine moving around on top of the pile. The unwatering equipment was also handled conveniently by the dragline machine. As soon as the excavation was completed, the foundation piling was driven. A steam hammer and its leads were suspended from the point of the boom, which was lowered to approximately a horizontal position. The hoist line was attached to the hammer for raising it in the leads, while the drag cable, passing through a pulley at the end of the boom, was used to snake over the piles and swing them into place in

the leads. It was a very simple matter to spot the piles, and then by allowing the end of the boom to rest on top of the leads the bottom was forced a foot or two into the gravel, and the whole was held rigidly in place, eliminating the necessity for guy cables. Steam for the hammer was supplied by the boiler on the dragline. Figure 47 shows this work under way. The foundation piles for the nearest pier are just being driven. The excavation has been made by the same dragline machine. The pier at

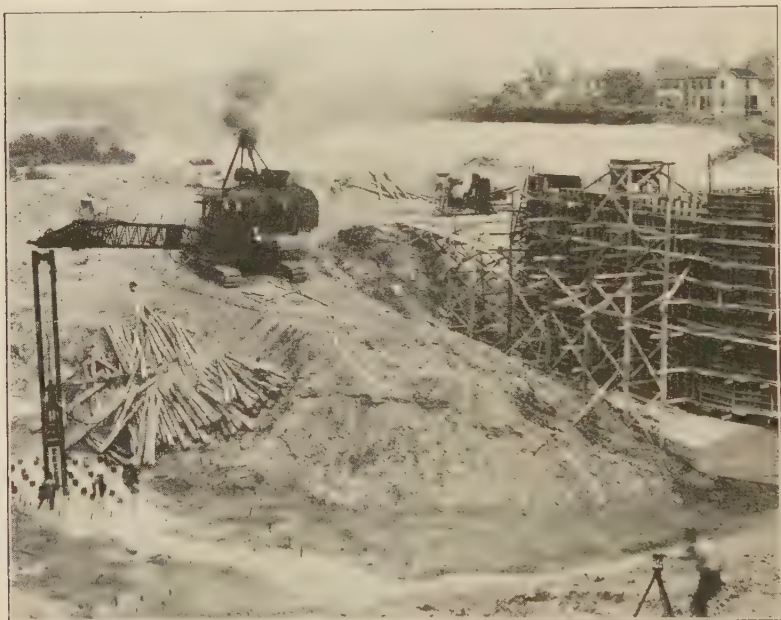


FIG. 47.—Excavating and driving piles for bridge piers.

This dragline machine made the excavation in open cut for the piers of a large seven-span reinforced-concrete highway bridge across the Miami River at Hamilton. The piles for the pier foundations were also driven by the same machine by hanging a steam hammer and set of leads from the end of the boom. In one 10-hr. shift 52 piles were driven to 18-ft. penetration.

the right is shown with the footing poured, and the forms are in place for the pier itself. Concrete for the footing was mixed on the site (the mixer may be seen just at the rear of the right-hand pier) and the concrete was also placed in the footing by the dragline machine. Later a cableway was erected, from which the remainder of the piers and the bridge itself were poured. After the concrete was placed in the piers and the forms removed, the

dragline machine cleaned up the cofferdam and used the material for backfill around the piers.

All these operations were handled effectively with the dragline, with a minimum risk of interruption or damage to equipment by floods. In case of high water which might overtop the cofferdam, the motors for the pump, or the whole pumping outfit, could be lifted out of place by the dragline machine, and then the machine itself could move over to shore on top of the cofferdam and remain ashore in safety until the flood had passed.

The unit cost of this excavation was figured on the basis of what would have been included within the usual sheet-pile cofferdam. In other words, no allowance was made for the extra excavation required for side slopes. On that basis the unit cost of excavation was \$2.11 per cubic yard. This is cheaper than it could have been done within sheeting, the time and expense of sheeting was saved, and the time of completing the whole job was much lessened by the open cut method. As to pile driving, 52 piles were driven to 18-ft. penetration in one 10-hr. shift. The unit cost including the piles themselves, was 58 cts. per lineal foot. The piles were of native hardwood and cost 28 cts. per foot delivered on the job. Unit costs include plant charge and field supervision.

At the time this work was done, common labor was receiving 46 cts. per hour; carpenters 65 to 75 cts.; dragline operators \$280 per month.

Dam Building.—A dragline was used to advantage on the construction of a small dam at Hamilton, Ohio. This is a low concrete overflow dam 5 to 9 ft. high, built as a barrier to prevent the drift of gravel into the improved channel. The dam has an apron downstream of concrete and concrete blocks, and a short apron upstream. There is a row of steel sheet piling 8 to 12 ft. deep along the edge of the upstream apron, and a row of round timber piles 15 ft. long driven 3 ft. center to center along the down-stream edge of the concrete apron. The overall width of excavation (up and down stream) is 72 ft.

The dragline started work on the far end of the dam and worked toward the center of the river, taking as the first section about half the width of the river. The excavated material was thrown up on either side to form cofferdams. An 8-in. unwatering pmup was sufficient to control the seepage. After the excavation had been finished, except for what hand work was necessary, the

dragline drove the row of timber piles in the same manner as has been described in the preceding paragraph. The steel sheet piling along the upper toe was then driven.

The progress in driving the round piles was about the same as that made on the bridge job. An average day's work for the driving of sheet piles was about 30 pieces per 10-hr. shift, 8 to 12 ft. penetration.

Road Grading.—In the southwest an earth road was built through a low, wet section by dragline. The conditions were

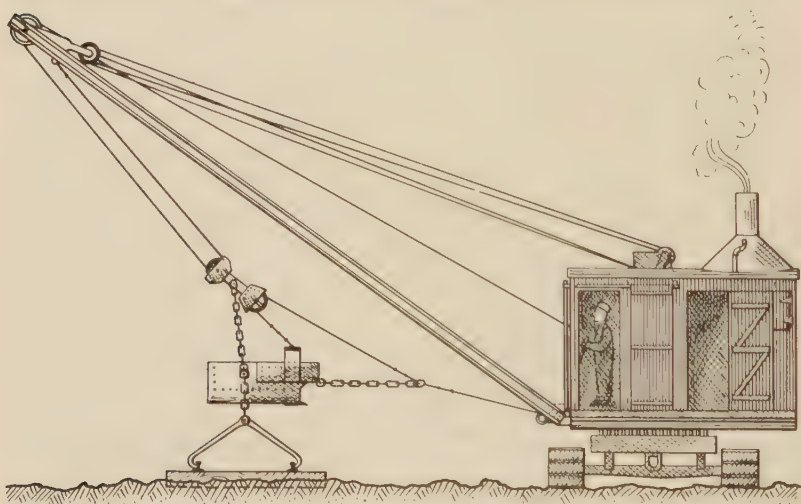


FIG. 48.—Dragline machine shifting track.

By this operation the track was shifted a distance of 2 or 3 ft., section by section. Then the machine moved back and made three or four additional runs in order to accomplish the full shift of approximately 12 ft. This method of shifting track turned out to be both speedy and economical.

such that tractor or team-drawn outfits could not work to advantage, due to the wetness of the material.

An 8-mile stretch of fill, averaging 3 ft. in height and 18 ft. wide on top, was built by a 1-cu. yd. caterpillar mounted machine. The entire crew consisted of a superintendent and four men, two of them operating the dragline. The output averaged 500 cu. yd. per 10-hr. shift. Considerable time was consumed in moving up.

Shifting Track.—On a large channel excavation job a small steam dragline on caterpillar traction was used successfully for shifting track on the dump. This dump was an extensive spoil

bank where hundreds of thousands of yards of material were wasted from channel excavation. The material was brought in on 12-yd. dump cars and distributed by a spreader, so when track was shifted it was moved over about 12 ft. For moving track the dragline machine was pulled up close to the track, the line of travel of the caterpillar being parallel with the line of track. A set of tongs was attached to the bucket and the machine was turned so that the boom extended over the track in the direction in which it was to be shifted. The tongs were fastened to the rail and when a section of the track was lifted, it swung out naturally away from the machine, due to the position of the boom and the manner of operation as illustrated in Fig. 48. This first bite accomplished a move of from 2 to 3 ft., the dragline then pulled ahead and repeated the operation until the whole line had been moved over that distance. It was necessary to move back and make three or four runs to accomplish the full shift of approximately 12 ft.

The time required for this operation was really very short, and this machine was quite effective for that purpose.

Other Uses.—Some other miscellaneous jobs that were handled satisfactorily by draglines were building track grades for construction tracks; building roadways for various purposes; assisting in the erection of larger machines or construction plant; unloading cars where a derrick was not available; and loading wagons, as is done by steam shovels.

CHAPTER VI

THE CABLEWAY EXCAVATOR AND POWER DRAG SCRAPER

The cableway excavator is essentially a digging, self-loading bucket which is drawn along a cable suspended from towers or anchorages. There are numerous types of cableway excavators, differing in the arrangement and structure of the towers and the methods of pulling the bucket. Perhaps the most common type is the slackline cableway, which is arranged so that the track cable may be loosened and tightened by the operator, thus allowing the bucket to be raised or lowered. Traveling tower cableways have both supporting towers mounted on trucks so that they can be moved along parallel to the banks. Tightline cableways have a main track cable which is kept taut; the bucket is pulled back and forth along this track cable and lowered and raised by other cable attachments.

Cableway excavators are used largely in gravel-pit operations where much of the digging is below water and where the material is passed through a screening plant. Other uses of cableway excavators are for levee construction, canals, reservoir construction, and stripping of overburden from mineral or coal deposits.

THE SLACKLINE CABLEWAY

For gravel-pit operation, the slackline cableway is the type commonly used. The usual installation has a fixed head tower or mast toward which the bucket is pulled. The other end of the track cable is fastened to a bridle cable stretched between two ground anchorages placed at right angles to the track cable. In front of the bridle is a short A-frame tower which supports a saddle sheave through which the track cable passes. The track cable has an adjustable connection to the head-mast or tower so that this cable may be slacked to lower the bucket and then tightened to provide a trackway on which the bucket is hauled in to the dump (see Fig. 49). The buckets (Fig. 50)

may be of various sizes, ranging from $1\frac{1}{3}$ - to $3\frac{1}{2}$ -cu. yd. capacity and may be equipped with teeth along the digging edge for use in hard material. The buckets dump from the digging end. A dump chain runs from the rear of the bucket up and over the sheaves in the bucket carrier, then forward and through a separate triangular sheave block known as the "dump block," which is connected by a short piece of chain to the bridle chains of the bucket. After passing over the sheave in the dump block,

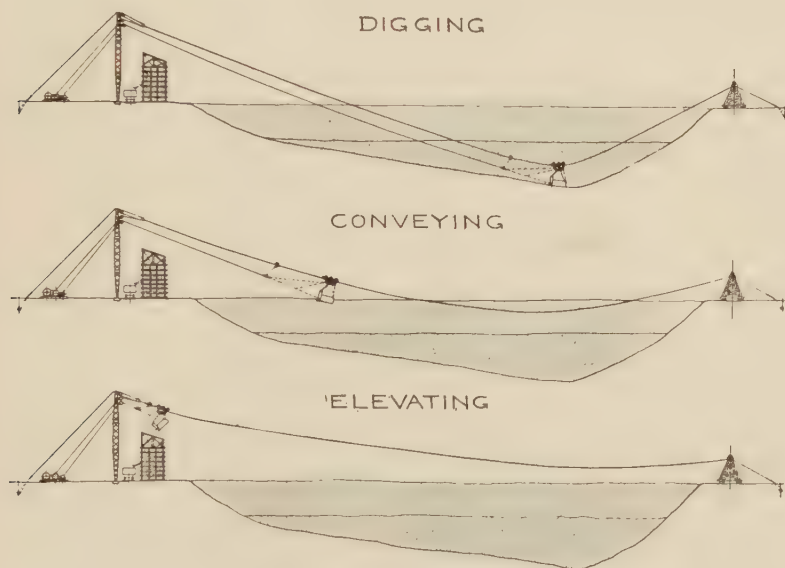


FIG. 49.—Sketch showing operation of slackline cableway.

These cross-sections show how the machine digs, conveys, elevates, and dumps in one continuous operation under control of an operator at the hoisting engine. (Reproduced by permission of Sauerman Brothers, Inc., Chicago.)

the dump chain returns upward and is attached to the traveler block which runs freely on the track cable ahead of the bucket carrier. When the traveler block reaches a "stop button," which is fastened to the track cable, the traveler block is prevented from moving farther along the cable and the resulting pull on the dump chain dumps the bucket. Adjustments of the position of the stop button or of the length of the dump chain make it possible to dump the bucket at any point desired (see Fig. 51).

Slackline cableway outfits, properly installed, can dig to a depth equal to one-third of the operating span and can elevate the excavated material to hoppers or spoil bank up to about 100 ft. above the ground level. The usual limits of total span are from 200 to 1,000 ft., and sometimes to 1,200 ft.

Double-drum hoists are used to operate slackline cableways. The power may be steam, electric, or gasoline. Plants operated

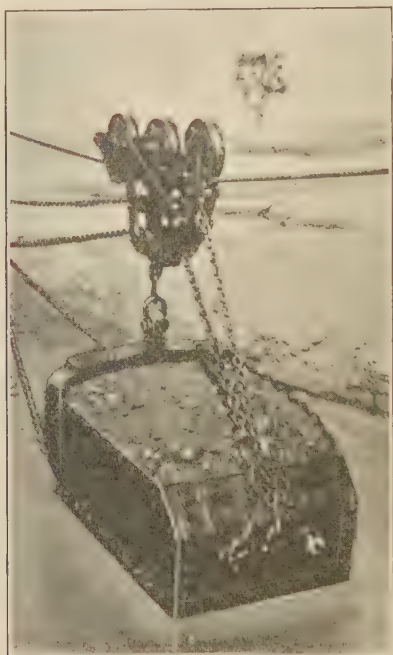


FIG. 50.—Loaded 1-cu. yd. slackline cableway bucket.

by electric or gasoline power may be operated by one man; where steam power is used a fireman will be needed in addition to the operator.

The output of a cableway excavator as used in gravel-pit operations will vary according to the installation and according to the use. The average time for a complete cycle of operation in actual digging will vary from 1 to $2\frac{1}{2}$ min., depending on the length of haul, conditions of digging, and the efficiency of the operator.

The following table, prepared by a manufacturer of slackline cableway excavators, indicates the approximate quantities of

ordinary sand and gravel that can be handled per hour for different spans and sizes of bucket. This table is based on operation by installations on which the average digging speed is 200 ft. per minute, the average conveying speed 600 ft. per minute and a gravity return speed of 1,200 ft. per minute.

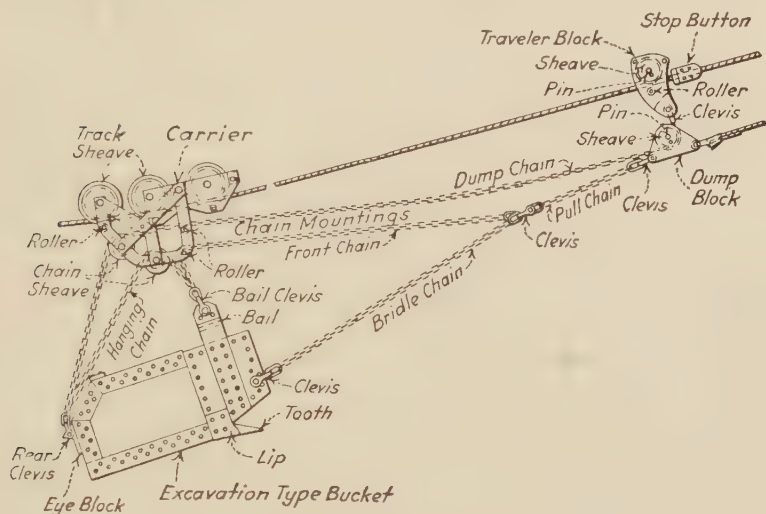


FIG. 51.—Diagram showing details of slackline cableway bucket-and-carrier assembly.

This sketch illustrates the arrangement of dumping the bucket. (Reproduced by permission of Sauerman Brothers., Inc.)

TABLE XII.—CAPACITIES IN CUBIC YARDS PER HOUR OF SAUERMAN CABLEWAYS ON AVERAGE HAULS OF VARIOUS LENGTHS OF SPAN WHEN USING DIFFERENT SIZES OF BUCKETS

Size of bucket, cubic yards	300-ft. span 200 ft. average haul	400-ft. span 250 ft. average haul	500-ft. span 300 ft. average haul	600-ft. span 350 ft. average haul	700-ft. span 400 ft. average haul
$\frac{1}{3}$	12 to 17	12 to 17	12 to 16		
$\frac{1}{2}$	19 to 26	19 to 26	18 to 24		
$\frac{3}{4}$	30 to 40	30 to 40	27 to 36	25 to 33	
1	38 to 52	38 to 52	36 to 48	33 to 44	30 to 40
$1\frac{1}{2}$	58 to 78	58 to 78	54 to 72	50 to 66	45 to 60
2	78 to 104	78 to 104	72 to 96	66 to 88	60 to 80
$2\frac{1}{2}$	97 to 130	97 to 130	90 to 120	83 to 110	75 to 100
3	114 to 156	114 to 156	108 to 144	99 to 132	90 to 120
$3\frac{1}{2}$	133 to 182	133 to 182	125 to 188	115 to 154	105 to 140

TABLE XII.—CAPACITIES IN CUBIC YARDS PER HOUR OF SAUERMAN CABLEWAYS ON AVERAGE HAULS OF VARIOUS LENGTHS OF SPAN WHEN USING DIFFERENT SIZES OF BUCKETS.—(Continued)

Size of bucket, cubic yards	800-ft. span 450 ft. average haul	900-ft. span 500 ft. average haul	1,000-ft. span 550 ft. average haul	1,100-ft. span 600 ft. average haul	1,200-ft. span 650 ft. average haul
1½	41 to 54	39 to 52	37 to 50	35 to 48	33 to 45
2	54 to 72	52 to 70	50 to 68	48 to 66	45 to 63
2½	68 to 90	65 to 87	68 to 85	60 to 82	57 to 77
3	81 to 108	78 to 105	75 to 102	72 to 99	69 to 93
3½	95 to 126	91 to 122	87 to 119	84 to 115	80 to 108

It should be remembered that ordinarily a gravel plant is not in continuous operation throughout a period of time and therefore the performance records given below do not necessarily indicate the capacity of the installations, but show what quantities were excavated over certain periods of working time on the various jobs.

METHODS AND PERFORMANCE RECORDS

A temporary cableway excavator was set up at Dayton, Ohio, to dig gravel for use in the construction of a concrete arch bridge. The span was 700 ft., the head tower mast was set up near the concrete distributing tower on one side of the river, and a movable dead-man on the other side of the river anchored the other end of the track cable. The digging bucket was of 1-cu. yd. capacity. The outfit was operated by a 40-hp. double-drum steam hoisting engine. Bins were set up so that the bucket dumped directly into them, dumping through a grizzly which rejected the large stones. This plant averaged about 350 cu. yd. per day.¹

A small plant was set up to excavate gravel for use in the construction of a concrete building at Waterloo, Iowa. The mast was set up on the river bank near the building site and the tail anchorage was on the opposite side of the river. A ¾-cu. yd. drag bucket was used, dumping over a screen. The plant averaged 250 cu. yd. per day.²

¹ *Eng. Contr.*, Feb. 21, 1917.

² *Eng. Contr.*, May 16, 1917.

For digging gravel for use on roads, a cableway excavator plant was installed in Logan County, Illinois. The cableway had a variable span and a 1-cu. yd. bucket was used. Power was furnished by a 9 by 10 steam hoist connected to a 35-hp. boiler. Practically all of the excavation was below water. In one hundred 10-hr. days, 20,000 cu. yd. were excavated, the average output being 200 cu. yd. per day. This does not represent the capacity of the plant, however, as it was not digging all of the time. Three men operated the plant. Coal consumption was $1\frac{1}{2}$ tons per day.¹

In Virginia a cableway excavator was used successfully for digging manganese ore from borrow pit. The material was dug by a $1\frac{1}{2}$ -cu. yd. bucket dumping into bins. About 100 tons of ore were handled per 10-hr. day by this plant.²

A basement excavation 70 by 200 ft., containing 12,000 cu. yd., was handled by a cableway excavator equipped with a $\frac{3}{4}$ -cu. yd. bucket and operated by a 3-drum, 75-hp. electric hoist. The material, which was gravel and clay, was dumped into a receiving hopper. The output on this job averaged 700 cu. yd. per 10-hr. day. One man operated the excavator.³

On a channel dredging job 1 mile long, with an average width of 200 ft. and an average depth of 8 ft., a cableway excavator handled the work economically. A movable, self-supporting 60-ft. head tower was used; the engine and boiler were mounted on the tower frame. The bucket was of 2-cu. yd. capacity. A movable anchorage was provided for the other end of the track cable. The span was 480 ft. This outfit averaged 500 cu. yd. per 10-hr. day, and one day it dug 801 cu. yd. of sand and gravel.⁴

A job of cleaning out and deepening a water supply pond near Beverly, Mass., was handled to advantage by a small slackline cableway installation. The pond is about 1,500 ft. long and from 300 to 500 ft. wide. It was necessary to do the work while water was kept in the pond. The material excavated was mud, peat, and vegetable growth. The cableway had a span of 675 ft., with a 200-ft. head mast; the tail anchorage was made to trees along the opposite shore of the pond. A 1-cu. yd. bucket,

¹ *Eng. Contr.*, Aug. 1, 1917.

² *Eng. Contr.*, July 18, 1917.

³ *Eng. News-Record*, Aug. 8, 1914.

⁴ *Eng. News-Record*, Feb. 17, 1915.

equipped with long, heavy teeth, handled the material. The cableway was operated by a double-drum steam hoist. The crew consisted of five men most of the time; a working foreman, engineer, fireman, and two laborers. Over 25,000 cu. yd. was handled by this plant; three set-ups of the head mast were necessary to cover the job.¹

The Howell Gravel Company, at LaGrange, Mo., has worked a gravel deposit of 100 acres with a slackline cableway plant having a 2-cu. yd. bucket and 700-ft. span. A two-speed steam hoist operates the plant. The material excavated has a depth of 10 to 30 ft., with a clay overburden which is not stripped off. A movable track hopper was installed to follow the cableway as it was moved along the pit. The total length of the pit was 1,400 ft. The short tail tower was built of timber and mounted on skids. The head mast was of timber and 90 ft. high. It was reported that this plant loaded from 42 to 45 cars of 50-ton capacity per 10-hr. day, and on one 22-hr. run 79 cars were loaded. This, however, was not everyday performance, as gravel plant operation is necessarily intermittent.²

A 700-ft. span slackline cableway with a $\frac{3}{4}$ -cu. yd. bucket was used near San Luis Obispo, Calif., to excavate sand from a river for use in concrete paving work. A 70-ft. mast was set up on the river bank, and a concrete deadman on the opposite shore held the tail blocks. The plant was operated by a 40-hp. steam boiler attached to a drum hoist. Sand was produced by this outfit much cheaper than it could be obtained otherwise,—the cost per cubic yard was about 25 cts. (1916).³

TRAVELING TOWER CABLEWAYS

Traveling tower cableways (see Fig. 52) are used for levee construction and sometimes for canal work. Both the head and tail towers are mounted on trucks, usually operating on narrow gage tracks laid alongside of and parallel to the stream or canal. The tracks are made in sections which are pulled ahead as the work advances. The main power plant, usually steam, is mounted on the head tower frame. On the tail tower is a smaller power plant to operate the track cable and to move the tower

¹ *Sauerman News*, March 1926.

² *Sauerman News*. May and June, 1926

³ *Eng. News-Record*, Vol. 74, No. 9.

along. Drag buckets of from 3- to 6-cu. yd. capacity are used on these outfits. The crew will consist of an operator, fireman, and necessary trackmen on each side of the stream.



FIG. 52.—Head tower of traveling-tower cableway.

The tower frame is mounted on sets of trucks which run on tracks laid parallel with the embankment. The power plant is carried on the platform at the base of the tower. (*Photo from Sauerman Brothers, Inc.*)



FIG. 53.—Crescent-type power drag-scraper bucket.

These buckets are also made V-shaped for certain kinds of work. They may be had in various sizes. (*Photo from Sauerman Brothers, Inc.*)

POWER DRAG SCRAPERS

The bottomless power drag scraper is a useful and adaptable excavator for certain classes of work, such as small gravel-pit operations, stripping overburden, cut-and-fill work for roadbeds,

as well as for the storage of bulk materials. These installations operate best over spans not exceeding about 300 ft., although 500-ft. spans are practicable.

A power drag scraper outfit consists of a bottomless bucket, which may be V-shaped or crescent shaped, often equipped with digging teeth on the bottom or cutting edge, which is pulled back and forth by a cable arrangement (see Fig. 53). One cable, called the load line, is attached to the front of the scraper bucket, and extends across the dumping point to a guide sheave and thence to the front drum of a two-drum hoist. Another cable



FIG. 54.—Loaded crescent-type bucket.

When loaded the bucket rides the load and is pulled to the dump. Then it is pulled back to the pit, leaving the load where desired. (*Photo from Sauerman Brothers, Inc.*)

is attached to the back of the scraper and extends to a tail block back of the excavation, and thence over a sheave to the rear drum of the hoist. A head post or tower supports the sheaves over which the in-haul and out-haul cables operate and the hoist and operator's platform are located behind this head post. The tail end of the cable may be supported on fixed or movable tail posts or towers.

In operation, the bucket is dragged forward through the material to be excavated until it is filled; then it stops digging because it rides on the load (Fig. 54). When the loaded scraper

reaches the dumping point, the haul-in drum is stopped, the pull-back drum is started, and the scraper is pulled away from the load back to the digging point.

The power for operating drag scrapers of the type described may be steam, electric, gasoline, or oil. One operator can handle the plant, except on steam installations, where a fireman will be necessary. Some help will be needed to shift head and tail posts when necessary.

The drag-scraper buckets are made in various sizes, ranging from $\frac{1}{3}$ - to 3-cu. yd. capacity.

When the power scrapers are used for dragging material into storage piles, high head masts are used, and the material is pulled up around the mast. Then when the material is to be withdrawn, it can be pulled down by the same rig.

Power-scraper installations are often used in connection with slackline cable plants in gravel pit operations; the scrapers are used to convey screened gravel into storage piles, and to reclaim this material as demanded.

POWER DRAG SCRAPER PERFORMANCE

A small gravel plant near Burlington, Wis., handles the excavation of material with a 1-cu. yd. power drag scraper installation. The output has averaged from 400 to 500 cu. yd. per 10-hr. day. The material is pulled out of a small hill of gravel to a hopper over the screening and washing plant.

At Jacksonville, Fla., a 9-cu. ft. power scraper, operated by a Fordson tractor, was used to grade up a large building site, 600 by 300 ft. About 10,000 cu. yd. of material was moved an average distance of 125 ft. to bring the entire area to an even grade. The front half of the area was low; the rear was piled up as high as 21 ft. with refuse. The tail frame of the scraper outfit was placed on the high ground and the head frame was set up near the highway in front of the area. When the scraper had graded all the area that could be reached at one set-up, two men carried the triangular head frame to its new position and the tractor moved over at the same time. Three men operated the plant. The average daily output was 300 cu. yd. in 8 hr.

Stripping a deposit of kaolin near Spruce Pine, N. C., was done by a 1-cu. yd. power scraper outfit. The overburden was as much as 24 ft. thick in places. The outfit operated over a span

of 400 ft., the motive power being a two-speed steam hoist. A mast 40 to 50 ft. high was used at the head end of the system to enable the scraper to build up a high spoil pile and the tail end was equipped with a rapid-shifting device. The cost of clearing off the stumps and overburden from an acre of ground, requiring the moving of about 15,000 cu. yd. of material, was about \$1,600. It was estimated that this cost was about one-fourth of the amount formerly expended for stripping, when stripping plows and team scrapers were used.

At Lannon, Wis., a small hill-gravel deposit was worked by a 1½-cu. yd. power scraper operating on a 500-ft. span. The



FIG. 55.—Crescent power-drag scraper in excavation.

Here the material is being stripped from the top of a hill and piled in a ravine.

scraper dug into the side of the hill and dragged the material down to a grizzly over a large hopper. The production of this outfit averaged about 500 cu. yd. per 10-hr. day, and as much as 700 cu. yd. was excavated in one day.

All of the above information regarding the operation of power scrapers has been obtained from *Sauerman News*, published by Sauerman Brothers, Inc., Chicago.

A power scraper was used to advantage in disposing of two large rock slides which occurred while the spillway excavation was being made for the Arrowrock dam in Idaho. This outfit consisted of a scraper bucket of the Bagley type, controlled by a ¾-in. cable, and operated by a standard three-drum, 75-hp. electric

derrick hoist. Either a 3- or a $1\frac{1}{2}$ -cu. yd. bucket was used. The length of haul was about 300 ft.

A large slide, containing about 25,000 cu. yd., occurred opposite the abutment of the dam and filled the spillway trench about half full for a distance of 100 ft. or more. The steam shovel which had handled the excavation was no longer available when this slide occurred, so the drag scraper arrangement was tried.



FIG. 56.—Quarry operations with crescent power-drag scraper. Blasted rock is being dragged from the quarry to the plant at the lower end of the pit.

and proved very effective. The material was hauled upgrade to a trap at the upper end of the trench, where two $1\frac{1}{2}$ -cu. yd. dump cars were loaded and took the material out to the dump. These cars traveled out by gravity and were hauled back by a line on another drum of the electric hoist. A $1\frac{1}{2}$ -cu. yd. orange-peel bucket, operated from a cableway, handled the larger pieces of rock from the slide to the trap.

Figures 55 and 56 illustrate other uses of power-drag scrapers.

CHAPTER VII

HYDRAULIC SLUICING

The hydraulic sluicing method for excavating sand, gravel, or earthy materials is not new, as it has been used in placer-mining operations for many years, and has had considerable use on several large projects, such as the Panama Canal and the Miami Conservancy District works near Dayton, Ohio. Under favorable conditions this method of excavating and transporting material is very satisfactory and is economical, especially where the material can be transported to embankment or fill by gravity. To carry on an excavating job by the sluicing method it is necessary to have, first, suitable material for breaking down; second, an ample water supply; and third, enough grade from the working face to carry away the material.

DESCRIPTION OF MONITORS

The material is broken down by hydraulic monitors, commonly called "giants," having nozzles from $2\frac{1}{2}$ to 5 in. in diameter. Figure 57 shows a large monitor, 15 ft. in length, which will throw a 5-in. jet of water with a "muzzle velocity" of between 140 and 150 ft. per second, varying with the head, at a working pressure of from 135 to 150 lb. per square inch. The upright post at the left end of the giant carries a beam, pivoted at its middle to the top of the post, and attached at its right-hand end to the stirrup piece shown mid-length of the barrel; the other end of the beam carries a counterweight to balance the weight of the barrel and nozzle. These swing in a vertical plane on two bolts to the right of the upright post. Water tightness is provided by a leather gasket riding on the spherical surface seen just to the left of the two flanges. Motion of the nozzle to right and left is provided by a ball bearing at the foot of the post, just above the flanges. A flat diaphragm gasket of leather provides water tightness at this joint, the water pressure being made to force the ring of the gasket into contact with its cast iron seat, so that the greater the pressure, the firmer the ring seats. Projecting

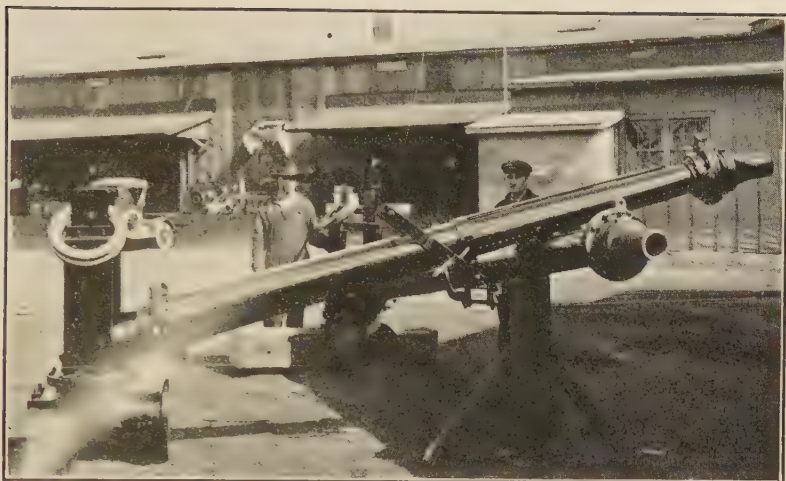


FIG. 57.—Large hydraulic giant or monitor.
The monitor shown is 15 ft. long and has a 5-in. nozzle.



FIG. 58.—Monitor in operation.
Material is being sluiced directly into a hydraulic-fill dam, being conveyed in a 15-in. pipe line laid on trestles.

bins within the barrel, parallel with the bore, in two sets, three in a set, concentrate the flow so that it emerges in a solid jet. The deflector nozzle, carried at the end of the barrel on two trunnions at right angles, compels the jet to do the mechanical labor of aiming itself. By inclining the deflector slightly to right or left, or up or down, by means of rods running back to the breech, the reaction of the jet swings the barrel in any direction desired. Skilful control of the nozzle is necessary and a competent operator should be employed, as the monitor can create great damage if it gets out of control. Figure 58 shows a monitor in operation.

GENERAL FEATURES OF OPERATION

The hydraulic giant is operated under nozzle pressures of from 60 to 150 lb. For dense clay material a $2\frac{1}{2}$ - to $3\frac{1}{2}$ -in. nozzle operating at 110 to 135 lb. pressure will usually be satisfactory, where the clay strata can be broken down by undercutting. For average mixed gravel and clay a 4-in. nozzle at around 100-lb. pressure works well, and for straight gravel containing considerable oversize stones, a 5-in. nozzle at 60- to 80-lb. pressure gives best results.

Water is supplied to the nozzles by centrifugal pumps. The size of the pumps to be used will be determined by the conditions on a particular job. Their capacity must be sufficient to overcome the velocity head, suction head, and friction head, as well as the static head or elevation of the nozzle above the source of water supply. Sometimes it is necessary to have an additional water supply to assist the water from the monitor in washing the material down the ground sluice after it is loosened by the jet.

In order to reduce the friction head as much as possible, a large-diameter supply pipe should be used between the pump and the monitor. Usually 12 to 15-in. pipe are used for most of the line, reducing to a smaller diameter for the part of the line near the monitor which requires frequent moving.

The grade of the ground sluice, or runway for the excavated material, should be usually not less than about 4 per cent, and a steeper grade is better. It should be remembered, however, that the flatter the slope the higher will be the face of the bank at any given distance from the pumps, and the higher the pit face, the greater the amount of material excavated. So an economical slope must be worked out for a given job.

A hydraulic monitor works most efficiently when placed as close as possible to the pit face which it is excavating, because the closer it is, the more effective the issuing jet will be. Also, for maximum efficiency, the jet must be directed against the base of the pit face, since then it works by undercutting. As the bank breaks off, the face of it recedes till it gets so far away that the jet no longer does efficient work. The supply lines must then be extended and the monitor moved up closer to the face. The operator only needs to be far enough away to be out of danger from the caving bank.

SLUICING METHODS

Sluicing methods, as developed on the Miami Conservancy District work, will be described in some detail. More than 2,000,000 cu. yd. of material were excavated by this method in connection with the hydraulic fill operations.

At the Taylorsville dam the surface material was a glacial till, a firm clay, with an admixture of gravel and rock fragments. On dry analysis about 60 per cent of this material is held on a 100-mesh screen. Of the material passing the 100-mesh a large percentage is very fine, in fact the material as a whole yields a considerable surplus of fines for hydraulic fill dam work. This till at Taylorsville had a depth of from 15 to 25 ft. below the surface. Underneath the till was a very hard blue clay which upon being broken up gave about the same mechanical analysis as the till. The wash-boring samples gave no indication that it was very different except in color. This blue clay was very hard and tough, however, and could not be broken up by the giants except after being blasted. Even then it was hard to handle. Many of these clay lumps passed down the ground sluice, through the dredge pump, and on through 1,000 ft. or more of discharge pipe, and came out in the shape of firm, hard balls the size of one's fist.

When this blue clay was first encountered it was drilled by means of churn drills rigged up to be worked with a pulley and tripod. This was not entirely successful, and was rather expensive; later, "snake holes" were jetted into the face near the bottom, nearly horizontal, about 10 ft. deep and spaced about 10 ft. apart. A number of them were shot at the same time. This method was more effective and cheaper than the other, but it required a longer face in the pit, so that the drilling and

shooting could be carried on at one place while the giants were working at another. Moreover, with a face more than 30 or 40 ft. high, this method tended to leave overhanging banks which were dangerous. At such places it was necessary to do some drilling from the top. During the latter part of the work well drills replaced the churn drills for this purpose. The well-drill holes were spaced about 20 ft. apart both ways and were loaded with about $\frac{3}{4}$ lb. of 40 per cent dynamite per cubic yard. The material was very hard to shoot properly, and none of the methods used were entirely satisfactory.

The water supply for these operations was taken from the river. For the giants, the supply was furnished at first by two 6-in. centrifugal pumps, each with a capacity of 1,400 g.p.m. against 150-ft. head. These were connected up so that they could be run either in series, giving 1,400 gal. at about 125-lb. pressure, or in parallel so as to give about 2,800 gal. at 60- to 65-lb. pressure. For the low-pressure water, to furnish the flow required in the ground sluice and a sufficient supply for the dredge pumps, a 12-in. centrifugal pump was installed, with a capacity of 5,600 g.p.m., against 80-ft. head. This low-pressure water was carried up to the top of the cut and allowed to flow over the face at various points, helping to wash down and soften the material in the face. After the blue clay was encountered it was necessary to increase the pressure for the giants, and two more 6-in. pumps were installed like those just described. These two pairs of 6-in. pumps were then worked in parallel, the two pumps in each pair being connected in series. This gave 2,800 gal. per minute, and supplied a 3-in. nozzle in the pit with a pressure of about 115 lb. Later a small two-stage pump was installed with the suction taken off the low-pressure water line, giving a chance to work another nozzle from this pump, and that worked so well, that eventually it was replaced by two 10-in. pumps, each with a capacity of 3,500 gal. per minute at 180-ft. head, thus giving another line with a pressure of about 175 lb. on a 3-in. nozzle, in addition to the high-pressure line from the two pairs of 6-in. pumps.

The giants used at first were standard No. 2 hydraulic monitors with $2\frac{1}{2}$ - to 3-in. nozzles. Later a No. 4 giant with $2\frac{1}{2}$ - to 5-in. nozzles was installed for operation under the higher pressure. It eventually became the practice to work two of these giants close together (see Fig. 59), using the larger one for the heavier

work, and the smaller for sweeping up the bottom and keeping the ground sluice clear. One of the secrets of success on this kind of work is to keep the nozzles close up to the face where they are much more effective than when working from some distance away. With a face as high as the one at Taylorsville, however, this is difficult because of the danger of caving of the banks.

The ground sluice at Taylorsville naturally took a grade of about 4 per cent. For short periods when an unusually rich

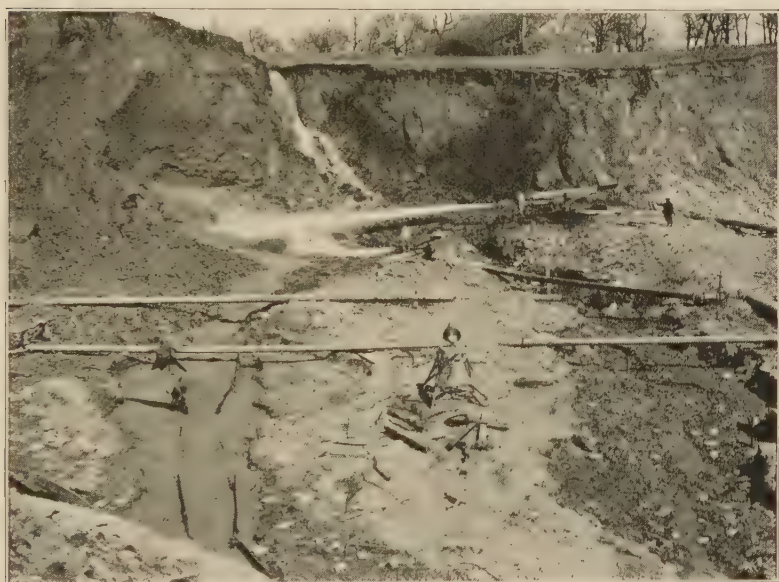


FIG. 59.—Sluicing in a borrow pit.

The low-pressure water may be seen coming down the face just beyond the two monitors. The large monitor at the right is operating under a pressure of about 175 lb. per square inch.

mix was being run, or when a large amount of sand and gravel was being carried, the sluicing would take a steeper grade temporarily, but would come back to about 4 per cent under normal operation. The normal flow of water in this sluice was about 16 cu. ft. per second. The percentage of solids usually averaged about 8 per cent, although at times they ran as high as 20 per cent. This ground sluice was simply a well-worn gully in the floor of the borrow pit, and its width was controlled at about

3½ ft. by means of plank sides staked down at places where there was a tendency for the flow to spread (Fig. 60).

This hydraulic sluicing at all of the dams was one part of the hydraulic fill job, and separate costs were not kept continuously on this portion of the work by itself. It has been possible, however, to get representative costs at most of the places where this method of excavation was used. The progress at Taylorsville varied considerably as the different classes of materials were encountered in the pit and as various methods were devised to meet the situation. The work was carried on by two shifts of

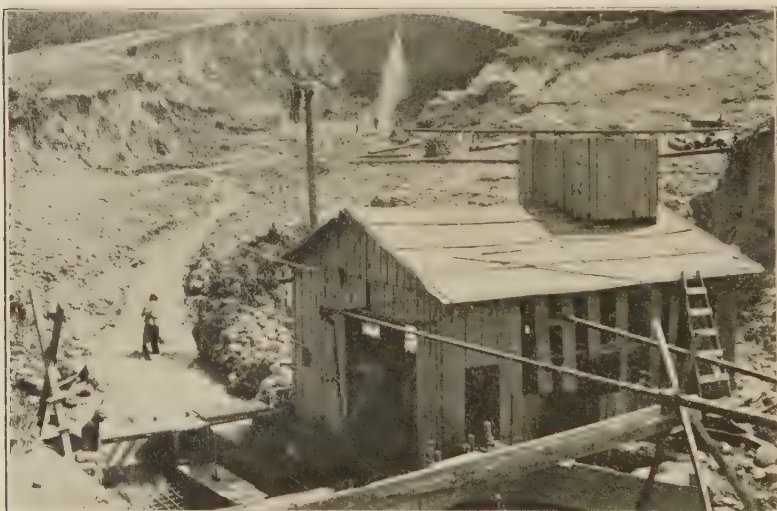


FIG. 60.—Hydraulic sluicing at Taylorsville dam.

The sluice ditch is in the foreground, with the grizzly bars just in front of the pump house to reject sticks and rubbish and large stones.

10 hr. each. During the first season, before the installation of the additional high-pressure pumps and the large giant, a good month's work was around 23,000 cu. yd., and the best month showed an output of only 28,500 cu. yd. After the installation of the large giant there was a marked increase in the monthly output, and during one month over 50,000 cu. yd. were taken out with the equipment here described. For short periods of a week or more, outputs of 150 to 200 yd. per hour were not uncommon, and quantities sometimes ran up to an average of between 200 and 300 cu. yd. per hour. On this kind of work, however, the average for a long period is very much less than the short-

time records would indicate. This is accounted for partly by the time lost in moving, and in trying to handle refractory material in the pit that was not thoroughly broken up by the shooting, but very largely because about the only way to tell the difference between a large and small output is by actual measurement. On most excavation jobs the rate of output shows for itself to an experienced observer, but with hydraulic sluicing the ground sluice looks about the same whether carrying a high or low percentage of solids. The difference between 6 and 12 per cent solids in the ground sluice is hardly noticeable without close inspection, although the difference in quantity of material being moved is 100 per cent. A job may run on for hours at a time, without it being realized that something has happened to cut down the output, unless given very careful attention by an experienced man. A skilful monitor man is absolutely essential for good results on work of this sort, especially in tough material like that described here, not only in order that maximum output may be maintained, but also that the pit may be kept in proper shape for continuous operation. To pick the soft places and make a big showing for a short period inevitably means a time of reckoning later on.

The following figures are given for two periods of work at Taylorsville: first, during the early work, before the best methods had been worked out for handling the hard clay, and before the additional high-pressure equipment had been installed; and, second, for a period after the installation of the additional high pressure pumps and the large giant.

COST OF SLUICING AT TAYLORSVILLE DURING THE EARLY PERIOD OF WORK,
QUANTITY MOVED, 243,500 CU. YD.

		Unit cost per cubic yard	Per cent of total
Superintendence and overhead.....	\$ 9,475.03	\$0.039	6.1
Labor.....	28,086.09	0.113	17.4
Electric power.....	10,324.68	0.042	6.5
Supplies.....	89,469.00	0.368	56.8
Plant depreciation.....	20,722.53	0.086	13.2
	\$158,077.33	\$0.648	

COST OF SIMILAR WORK AT TAYLORSVILLE AFTER INSTALLATION OF
ADDITIONAL HIGH-PRESSURE EQUIPMENT
(Quantity moved, 164,800 cu. yd.)

		Unit cost per cubic yard	Per cent of total
Superintendence and overhead.....	\$ 3,620.77	\$0.022	6.2
Labor.....	23,343.36	0.143	40.2
Electric power.....	9,802.31	0.060	16.8
Supplies.....	13,680.83	0.084	23.6
Plant depreciation.....	8,195.00	0.047	13.2
	\$58,642.27	\$0.356	

Labor was being paid 38 to 46 cts. per hour, blacksmiths 60 cts. per hour, monitor men 55 to 60 cts. per hour, pump runners 50 to 55 cts. per hour, all men on an hourly rate being given 11 hr. pay for 10 hr. work (time and a half after 8 hr.).

These costs include overhead, full plant depreciation and all costs properly chargeable to the work. The item for supplies includes the cost of explosives. These figures cover the cost of breaking down the material in the borrow pit and transporting it through the ground sluice as far as the dredge pump sumps. A comparison of these two sets of cost figures illustrates how costs may be reduced, in material of this sort, by the installation of sufficient high pressure equipment. The cost of power per cubic yard was increased 50 per cent, and labor was increased slightly, but the net result was a marked reduction in unit cost because of increased output.

Hydraulic Sluicing at Lockington Dam.—The borrow pit at Lockington was so located as to include a deposit of sand and gravel at one side of the pit while at the other side the material was mostly a blue clay. The sand and gravel, with its overburden of clay and loam, furnished a good percentage of the fines required for the hydraulic fill. Additional fines were needed, however, and the blue-clay section of the borrow pit was drawn upon for that purpose. The sand and gravel was easily broken down in the pit by the hydraulic giants, and was good material to sluice except that it contained a rather high percentage of

cobbles and boulders. The blue clay was more difficult to handle, although it was not as hard as that at Taylorsville, and did not require blasting. The material was so located that most of it could be sluiced on 4 per cent grades, although at the latter end of the work these grades had to be flattened somewhat in order to secure all the material that was required, and some sand and gravel that lay too low to be sluiced out was thrown up to a higher elevation by a dragline machine.

The water supply for these operations was secured from a canal which passed not far from the borrow pit. The low-pressure supply was taken to the edge of the pit by means of a ditch, and was distributed around the edges of the pit by lateral ditches which were built as needed. For the supply to the giants two 8-in. centrifugal pumps, each rated at 1,950 g.p.m. against 100-ft. head, were set up so that they could be operated either in series or in parallel, or separately. In addition to these, a 14-in. centrifugal pump was set up on the line as a booster. With this pump on the line it was possible to operate two nozzles in the pit at pressures as high as 175 lb.

As the work went on, it was found that more effective work could be done in the pit if the flow through the ground sluice could be increased. There was no more water available from the canal, but there was ground water seepage into the dredge pump sump (dredge pumps were used to pump the sluiced material into the dam) which not only forced the dredge pumps to handle more water than was economical, but raised the elevation in the sump, and therefore affected the grades at the lower end of the ground sluice. A 15-in. centrifugal pump, with a capacity of about 10 sec.-ft., was set up at a place where it would pull down the elevation of ground water in the main sump, and the discharge from this pump was taken up to the ditch system carrying the low pressure supply. Thus about 10 sec.-ft. of additional flow was continuously circulated through the ground sluice, adding materially to its transporting capacity.

The giants used at first were standard No. 2 hydraulic monitors with $2\frac{1}{2}$ - to 3-in. nozzles. Later a No. 4 giant with $2\frac{1}{2}$ - to 5-in. nozzles was brought in for use on the clay side of the pit. This large giant, operating at 175-lb. pressure with a $2\frac{1}{2}$ -in. nozzle, broke down the blue clay very effectively.

As has been said, the ground sluices were laid out originally for 4 per cent grades. It afterwards became necessary to flatten

these grades in order to get more of the material from the bottom of the pit, and by careful handling these sluices were actually operated satisfactorily on grades as low as $2\frac{1}{2}$ to 3 per cent. The percentage of solids averaged from 4 to 7 per cent over long periods, although at times very much higher percentages were carried during short periods. There were many factors entering into this job, because it was a part of the hydraulic fill at the dam, which would not have been present had it been a straight



FIG. 61.—Borrow pit at Lockington dam.

This shows the dragline machine piling up material which lay too low in the pit to be sluiced direct to the sump.

sluicing job. The selection of suitable material, the proper proportioning of coarse and fine materials, the synchronizing of ground-sluice discharge with the dredge-pump capacities, all tended to slow up the sluicing operations in the pit, and to cut down the percentage of solids carried.

Towards the latter end of the job when it became apparent that the pit would not yield gravel enough for the completion of the dam, a dragline machine was installed, and passed up into the pit some material which lay too low to be reached by the sluicing. Figure 61 shows this machine and the pile of gravel which it has thrown up. At the time this picture was taken the

ground sluice was flowing along the edge of this pile of gravel. By properly manipulating the ground sluice it was possible to undercut the gravel pile and gradually work practically all of the material down to the sump without the use of giants at all. Figure 62 shows this process in operation and indicates how the sluice ditch could be crowded into the loose gravel bank by use of diagonal shear boards on one side.



FIG. 62.—Sluice ditch undermining loose gravel.

This illustrates the method of undercutting the loose gravel piled up by the dragline machine (see Fig. 61). By the use of the diagonal shear boards this ditch could be crowded into the loose gravel bank, thus undercutting the gravel pile and working the material down to the sump.

The work in the pit at Lockington was carried on by two 10-hr. shifts. A good month's work was between 50,000 and 60,000 cu. yd. The best month showed an output of 80,000 cu. yd. The average cost of this sluicing for the whole period of work was about 35 cts. per cubic yard. To show what may be done in material like that at Lockington under favorable conditions the following costs are given for a period of 4 mo., when the condi-

tions were favorable for a large output and when no unusual delays occurred.

COST OF SLUICING AT LOCKINGTON FOR 4-MONTH PERIOD
(Quantity moved, 280,600 cu. yd.)

		Unit cost per cubic yard	Per cent of total
Superintendence and overhead.....	\$ 3,500.00	\$0.012	5.8
Labor.....	27,306.10	0.097	46.6
Power.....	16,353.72	0.058	27.9
Supplies.....	5,596.19	0.020	9.6
Plant depreciation.....	5,981.53	0.021	10.1
	\$58,737.54	0.208	

During this period the wages for laborers were from 35 to 40 cts. per hour, blacksmiths 60 cts. per hour, monitor men 55 cts. per hour, pump runners 50 cts. per hour, with 11-hr. pay for 10-hr. shift, or time and a half after 8 hr.

The above figures might be taken as representative for the approximate cost of a straight sluicing job in gravel, where there is a free getaway for the material and no probabilities of delays because of other dependent features of the job. They should not, however, be considered as representative of sluicing costs in connection with hydraulic-fill dam construction, where the sluicing operations continually have to be arranged and controlled to suit the requirements of the hydraulic fill itself.

Hydraulic Sluicing at Huffman Dam.—The main borrow pit at Huffman was so deficient in fines that the need of supplying this deficiency became apparent very soon after the work started on the hydraulic-fill embankment. A borrow pit was available on the hillside at one end of the dam, where the bedrock was overlaid with a deposit of glacial till and blue clay which apparently could be handled economically by hydraulic sluicing. A part of the material in this pit could be sluiced direct into the embankment of the dam. From this pit about 80,000 cu. yd. were put into the dam by that method. The rest of this additional material, or about 130,000 cu. yd., was handled by sluicing to a dredge pump and pumping into the dam.

The water supply was taken from a channel leading from the river to the foot of the hillside slope. Two 10-in. centrifugal pumps, each with a capacity of 3,500 g.p.m. against 180-ft. head furnished water to the giant. These pumps were connected in series and gave a pressure of about 125 lb. on a 5-in. nozzle in the pit.

Consider first the portion of this material that was handled by direct sluicing. The material in the bank was broken down by the hydraulic giant and carried by a ground sluice to a convenient point in the pit, where it was collected and fed through a small V-shaped collecting basin into a line of 15-in. dredge pipe which took it out to the embankment of the dam. This pipe was used in preference to an open flume for several reasons: first, the pipe was available, and there were other uses for it on the job, so that the only charge against this work would be the depreciation; second, a pipe line is much more flexible than a flume, and is more easily handled as the embankment is raised; third, the pipe line could follow the natural grade of the hillside, eliminating the necessity of extensive trestle work, and could be carried out practically level on the dam embankment for long distances operating under all the head available, regardless of changes in slope.

The material in this hillside pit varied considerably as regards its clay content, and the material being delivered could be selected as desired. With a short length of discharge line, and therefore a steep average grade, the material containing the highest percentage of sand and gravel was selected in the pit. As the discharge line was lengthened material of higher clay content was sent down, until when the discharge line reached its extreme length the material sent down through it was about 80 per cent clay. This pipe line would carry such material satisfactorily on an average grade as low as $1\frac{3}{4}$ per cent.

The small crew of men required on this work was a noticeable feature of the operation. The usual crew consisted of five men:

1 pump man looking after the two pumps.

1 monitor man, on the giant.

1 man on the open sluices in the pit, who also gave the required attention to the collecting basin at the pipe inlet.

2 men on the dam at the discharge end of the pipe.

An average month's work in this pit was about 12,000 to 15,000 cu. yd., working two 10-hr. shifts per day, as was done most of

the time. The average cost of the 81,000 cu. yd. moved by direct sluicing was 49.8 cts. per cubic yard, subdivided approximately as follows:

	Unit cost per cubic yard	Per cent of total
Superintendence and overhead.....	\$0.018	3.7
Labor.....	0.142	28.5
Electric power.....	0.208	41.7
Supplies.....	0.019	3.8
Plant depreciation.....	0.111	22.3
	\$0.498	

which includes not only the sluicing itself but also transporting through the pipe line and delivering on the dam. The cost of sluicing alone, taking the material only as far as the pipe inlet, would be about 44 cts. per cubic yard in this case.

The 129,000 cu. yd. of material in the lower part of the hillside pit was handled in the same manner as that just described as far as pit operations were concerned, but a dredge pump was required to boost the material on to the dam. This pump, instead of picking up the material out of the sump as was done in the main sluicing operations at Taylorsville and Lockington, was set into the discharge line from the pit, operating as a booster in that line. In other words, the material from the pit was fed direct into the suction of the pump. The distance from the collecting basin to the pump was about 400 ft., and the average grade of the line in this section was $4\frac{1}{2}$ per cent. The 100 ft. of line next to the pump was made up with airtight joints so that if necessary the pump could exert a suction pull through that part of the line to clear out an excess load of heavy material that had a tendency to settle in the line. Sufficient grade in the suction line was important. At first an installation was made with a grade of only $2\frac{3}{4}$ per cent, which proved unsatisfactory due to the frequent clogging of the line.

Ordinarily, in an installation of this kind, the giant would not furnish water enough for most economical results in the ground sluice or at the dredge pump. This material, however, being mostly clay, was not particularly easy to break

down with the giant; after being broken down it was easy material to sluice, and the ground sluices were short. For these reasons no additional sluicing water was required. At one time an additional supply was provided temporarily, but this was discontinued as apparently it was not necessary. The average grades of the ground sluice in the pit were about $4\frac{1}{2}$ per cent.



FIG. 63.—Hydraulic monitor nozzle and deflector.

This is a close-up of one of the large monitors operating at a pressure of 125 lb. per square inch. The operator is holding the deflector rod. (See page 152.)

There was some trouble, of course, because of the direct feed into the suction of the dredge pump. The capacity of the collecting basin was small, and therefore gave very little regulation between ground-sluice discharge and pump discharge. The dredge-pump man had to be on the alert every minute to avoid trouble from temporary variations in flow, due to spread or diversion of the ground sluice in the pit, clogging, etc. As the discharge through the giant was uniform, and, as that was the only

source of water supply in the pit, it was possible for the dredge-pump man to operate quite satisfactorily in spite of the difficulties mentioned. The job was not large enough to warrant a real regulating basin at the inlet to the suction pipe.

The working face in this pit was not more than 12 or 15 ft. in height. Therefore it was feasible to work close up with the giant, thereby getting the most effective work out of it. It was found that if the bank had receded 50 or 60 ft. back from the nozzle, the effectiveness of the giant was very much reduced. If this face had been much higher, so that the danger of caving had prevented the giant working so close, it is probable that the material in the pit would have required blasting. Figure 58 shows part of the operation in this hillside borrow pit, and Fig. 63 is a close-up of the nozzle of the hydraulic giant operating at about 125-lb. pressure.

The progress of work in the lower part of the pit averaged about 16,000 to 18,000 cu. yd. per month, two 10-hr. shifts per day. This was somewhat better progress than the first work showed, largely because the men were broken in to the job, and some of the difficulties had been ironed out. The average cost of this 129,000 cu. yd., including sluicing to the dredge pump and pumping over to the dam, was about as follows:

	Unit cost per cubic yard	Per cent of total
Superintendence.....	\$0.020	3.4
Labor.....	0.155	26.3
Electric power.....	0.261	44.3
Supplies.....	0.037	6.2
Plant depreciation.....	0.117	19.8
	\$0.590	

The cost of sluicing alone, in this part of the pit, did not average more than 40 cts. per cubic yard.

Hydraulic Sluicing at Germantown Dam.—Sluicing operations at Germantown dam were an afterthought, and no consideration was given to them in the layout of the construction plant. After the work on hydraulic fill was well under way, it developed that the proportion of fines in the borrow-pit material was hardly

sufficient to furnish the amount required for the impervious core of the dam. Moreover, the dredge pumps had a capacity greater than that of the dragline machines in the borrow pit. Sluicing clay from the adjacent hillside into the sump would help both these conditions, and probably decrease cost as well as improve progress.

The amount of this clay that could be used, however, was limited, therefore an elaborate or expensive installation for getting out this material was not warranted. As a matter of fact, the installation was very simple. The giant at one end of the hog box was supplied with water under 50- or 60-lb. pressure by means of an 8-in. pump with a capacity of 1,950 g.p.m. at 140-ft. head. The pipe line supplying this giant was extended on up the hill to the pit, and at a convenient point along the line another 8-in. pump, of the same capacity of the one just mentioned, was installed as a booster. This furnished 1,950 g.p.m. at the pit with a pressure of about 80 lb. on a $2\frac{1}{2}$ -in. nozzle.

The material was a glacial till, and while neither the quantity of water nor the pressure available were as much as would be required for most economical sluicing, this layout answered the purpose very well. The output varied considerably during different periods, largely because this pit was operated as an adjunct to the main pit, to fill in the deficiency of fine materials as required. The maximum monthly output was about 16,000 cu. yd. The unit cost varied from 20 to 50 cts. per cubic yard.

It should be kept in mind, while considering the methods and costs here described, that none of these jobs were operated under favorable conditions as sluicing jobs. In every case they were essentially a feature of hydraulic-fill dam construction, where the selection of materials, or quantities handled, were dependent primarily on the requirements at the dam. None of the materials were ideal for sluicing operations; most of them were just the opposite. Moreover, certain selection of materials had to be made in the pits, to furnish more fines or less fines, according to the demands of the dam, which always meant higher costs in the pit to a greater or less extent. Again, whenever a shut down was necessary at the dredge pump, or a suction or discharge line was plugged, the sluicing had to stop immediately until the pump could start up again. Hence, much loss of time, and added expense, resulted from causes outside of the sluicing job

itself. These figures are given, therefore, not as examples of typical sluicing jobs, but rather to show what can be done by sluicing, under conditions not by any means favorable, and still compete successfully with other excavating methods. It is doubtful, if, in any of these cases, the work could have been done as economically by any other method, and still fit in with the rest of the job.

Sluicing at the Calaveras Dam, California.¹—Sluicing operations were used to excavate the material for a large hydraulic-fill dam in California, the Calaveras dam of the Spring Valley Water Company. Eight borrow pits were opened up in the vicinity of the dam, and some sluicing was done from each of these. Practically all of the hydraulic fill in the dam had to be pumped, as only one of the borrow pits was at an elevation sufficient to deliver the material by gravity. The material was gravel, sand, shale, sandstone, and clay.

Motor-driven centrifugal pumps were used. On a barge in the reservoir above the dam was a three-stage, 8-sec.-ft. pump direct connected to a 500-hp. motor. The water was pumped through 12-in. steel pipe, and was delivered to the pits at a nozzle pressure of 75 lb. Another station was in the canyon below the dam, and received its supply through a suction pipe laid through the outlet culvert. This installation consisted of two units, one with a capacity of 8 sec.-ft. against 400-ft. head, and one of 4 sec.-ft. against 550-ft. head. Water from the smaller pump was delivered at 75-lb. head at the nozzle and was used for cutting the banks. Water from the second unit was used to help carry the material to the dam. At first 4-in. hose and 2-in. nozzles were used, but it soon became apparent that greater efficiency would be secured by concentrating the streams, obtaining in this way greater cutting effect and increased yardage.

The jets were directed against the toe of the borrow-pit bank, which was undermined, causing it to cave in, and thus breaking up the soil. The grade of the pit floor varied from 6 per cent with fine material to 20 per cent where the material was coarse and rocky.

On the two sluicing units, each working two 10-hr. shifts, the total number of men employed was 15 per unit per shift. This

¹ This information was obtained from a paper by G. A. Elliot, Engineer, The Spring Valley Water Company.

number includes the men necessary to move pipe lines, tend pumps, etc. The average output per day was 3,600 cu. yd., transported an average distance of 3,000 ft. to the dam.

Sluicing on the Jackson Street Regrade, Seattle.—Hydraulic excavation was done on a large scale at Seattle, Wash., in connection with extensive grading operations in that city. There were three major projects, one of which is known as the Jackson Street Regrade. This job covered 56 square blocks, 29 of which required excavation and 27 were filled. The total excavation was about 3,350,000 cu. yd., and the total embankment amounted to about 3,115,000 cu. yd. This work was done during the years 1907 to 1909 at a total cost of \$915,000. Original grades of from 7 to 15 per cent on Jackson Street were reduced to 5 per cent, the cuts ranging from 10 to 94 ft. Slopes of the cuts were 1 to 1, and embankment slopes were $1\frac{1}{2}$ to 1. The $1\frac{1}{2}$ -to-1 supporting slope for the streets was carried up by means of slope boards, consisting of two 1- by 12-in. boards nailed one above the other to posts. As the fill reached the top of one set of these boards, another row was started about 2 ft. back of the preceding one.

The water supply for sluicing was obtained from several sources, one was a city reservoir which supplied about 6,000,000 gal. per day, another from a lake, and a third from Elliott Bay, about $1\frac{1}{4}$ miles from the center of the job. The pumping plant at Elliott Bay consisted of four 10-in., five-stage centrifugal pumps, direct-connected to two 650-hp., 2 phase, 2,000-volt a.c. motors. The pump casings were of cast iron, with bronze impellers, designed to resist the corrosive effect of the salt water. They were constructed with 12-in. suction lines and 10-in. discharge. The combined efficiency of the plant was about 63 per cent and the capacity, when running at 690 r.p.m. under 375-ft. head, was 8,400 gal. per minute. A 24-in. banded wood-stave pipe line conveyed the water to the giants; this line was 6,100 ft. long. At a velocity of 5.2 ft. per second, the friction loss in this line was 0.258 lb. per 100 ft. of pipe.

When the excavation had been opened up, the 24-in. supply line from the salt-water pumps was run into the pit parallel to the face of the cut and seven or eight 12- to 14-in. distributing lines were run up at right angles to the big main to supply the giants at the face of the bank. The giants were fitted with removable nozzle tips ranging from 3- to $4\frac{3}{4}$ -in. diameter. The

working pressure at the giants was from 60 to 100-lb. per square inch.

The material was a hard blue clay of glacial origin, overlaid with a top soil of from 6 to 12 ft. of soft yellow clay, which made a very efficient lubricant for the heavier under strata. The stream was always directed at the toe of the bank in order to undermine the face and cave it in, thereby breaking up the material so as to eliminate as much blasting as possible. Constant shooting was necessary, however, to assist in breaking up the material. From 200 to 500 lb. of 20 per cent stumping powder was used daily in charges of from $\frac{1}{2}$ to 2 lb. per hole.

The sluiced material was transported almost entirely by wood stave pipes of 18- to 20-in. diameter. At the ends of the pipe lines, which were kept about 100 ft. from the face of the cut, wooden penstocks were constructed of 2- by 12-in. lumber. These were about 12 ft. long, $21\frac{1}{2}$ ft. wide and 4 ft. high. The material was directed into the penstocks by means of shear boards. A grizzly or screen was placed at the entrance of the penstocks to exclude debris and oversize material. The grades varied from 2 to 8 per cent. Several lines were in use continually carrying the material to different portions of the sump, and the length of pipe lines varied from 300 to 5,875 ft., the average being about 2,000 ft. Owing to the long haul and low grades, the percentage of solids carried was not high; it ranged from 2.6 to 19.2 per cent and averaged 6.75 per cent.

All of the work was carried on in three 8-hr. shifts, with a shut-down over Sunday. Laborers were paid from \$2 to \$2.40 per 8-hr. day, and monitor men from \$2.75 to \$4 per 8-hr. day. The contract price for the work was 10 cts. per cubic yard for excavation and 15 cts. per cubic yard for embankment. The total plant charge was about \$70,000, including \$35,000 for pumps, \$14,000 for water pipe line, \$12,000 for discharge pipe line, and \$9,000 for miscellaneous tools and equipment.¹

Sluicing in Strip Mining.—For stripping an open-pit iron mine in the Northwest the sluicing method was used to advantage. Water was pumped $1\frac{1}{2}$ mile through 12-in. pipe to the pit where it was nozzled down to 3 in. and directed against the spoil bank with a nozzle pressure of 65 lb. per square inch. The material, consisting of sand and gravel, was washed to a sump. The water used in washing down the material was pumped to the pit by a

¹ *Eng. Rec.*, Vol. 65, No. 18, May 4, 1912.

two-stage centrifugal pump direct-connected to a 300-hp., 2,200-volt a.c. motor. The pressure at the pump was 145 lb. per square inch. The output on this job was 87,000 cu. yd., and it was all moved in forty-two 10-hr. shifts, averaging 2,075 cu. yd. per shift.¹

Small Sluicing Job.—The U. S. Reclamation Service installed a small sluicing plant for sluicing 2,750 cu. yd. of clay into the main canal of the Grand Valley irrigation project in Colorado. The plant consisted of a hydraulic giant with 3½-in. nozzle, a two-stage centrifugal pump with 6-in. discharge, driven by a 75-hp. motor, and the necessary pipe, etc.

Two men operated the plant. The material excavated was a dense, tough clay. The stream from the giant was kept moving over the face of the bank to remove the clay in thin layers so that it would sluice readily. A short wooden flume delivered the material into the canal, it being desired to silt up the porous sides with the clay. For every cubic yard of clay 340 cu. ft. of water was pumped. The rate of excavation was 33 cu. yd. per hr. for 48 hr. of actual operation. This is a low rate, but the clay was tough and it was desired to reduce it to a very fine mud.

The cost of this job was 29.1 cts. per cubic yard, of which 6.7 cts. was for installing plant, 3.9 cts. for labor operating, 6.8 cts. for power (electric), 3.7 cts. for removing plant, 7.9 cts. for engineering, transportation expense, etc.²

Sluicing on Highway Work.—Hydraulic sluicing was applied to the moving of two heavy highway cuts into fill on a highway grading project near Vancouver, Wash. The material was mostly sand and the total length through the two cuts was about 1,800 ft. One of the fills, about 1,000 ft. long, averages 50 ft. in height. The first and largest cut contained 101,000 cu. yd. Sluicing was started on the down-hill side of this cut. First a ditch was cut through the hill; then the giant began at the upper end of the cut and worked down, widening to full width. Finishing was done by fresno outfits. A 10-in., two-stage centrifugal pump with a capacity of 3,000 g.p.m. against a 210-ft. head supplied the giant for this work. Water for the sluicing was obtained by ponding a small nearby creek.

The second cut was separated from the first by a deep ravine, and the material from this second cut had to be transported to

¹ *Eng. Contr.*, June 18, 1919.

² *Eng. Contr.*, Dec. 19, 1917.

the main fill below the first cut. To accomplish this a 14-in. wood stave pipe was extended into cut No. 2 through which the pump delivered to a 3-in. nozzle. The sluiced material was diverted by shear boards to a 17-in. riveted steel pipe which carried it to the fill. A 50-hp., 8-in. centrifugal pump was used to boost the material down to the fill.

The pump was placed at the lower end of cut No. 2 with its intake pointed uphill toward the material to be sluiced and the discharge line ran across the ravine and through cut No. 1. As the sluicing giant moved up the cut, additional lengths of pipe were added to the suction line until the maximum effective length of 200 ft. of suction line was reached. Then the pump was moved up the cut, thus lengthening the discharge line and shortening the suction line.

The sides of the cut were undercut well beyond the width of the roadbed to a point where the material remaining above was just enough to fill the extra cut below, figuring on a $1\frac{1}{2}$ to 1 slope. This upper section was then drilled along its face to a depth of 10 or 12 ft. with a 4-in. post-hole drill and loaded with four to eight sticks of 20 per cent stumping powder. These shots jarred the sandy material loose and it slid down on a $1\frac{1}{2}$ to 1 slope.

In the cut two men were used for the sluicing work; one handled the giant. One man controlled the fill and another controlled the settling pool. A crew of four to seven men handled the shear boards used on the fill. The work was carried on 24 hr. per day.¹

¹ *Eng. News-Record*, Vol. 97, No. 20.

CHAPTER VIII

DREDGING

A dredge is an excavating machine adapted to digging materials which are under water. It is usually mounted on a floating hull and may or may not be self-propelled. Some dipper dredges operate on land instead of from floating hulls. For many years the dredge, in its various forms, has been used successfully for certain classes of excavating work. Chief among these operations are deepening, straightening, and cleaning out channels and harbors, the construction of ditches and canals, the reclamation, by filling, of wet or partially inundated lands, placer mining, and the excavation of sand and gravel from submerged pits.

There are several types of dredges, each particularly designed for certain kinds of work. The types used most extensively in this country are the dipper dredge, the ladder dredge, the grapple or grab-bucket dredge, and the hydraulic dredge. Each of these types will be described in some detail, with a discussion of the usual methods of handling them.

In general, the floating-dipper dredge, which is in effect a power shovel on a boat, is most useful where the material to be dug is hard and compacted or obstructed by stumps and debris. Dipper dredges are not adapted to digging at greater depths than about 50 ft. These dredges are used largely on canal and ditch work through wooded country and for certain river and harbor improvement jobs.

In this country, the ladder dredge is used almost exclusively in placer-mining operations for the recovery of gold, tin, platinum, and other metals, though some sand and gravel excavation on the Ohio and other large rivers has been handled by ladder dredges. Self-propelled ladder dredges are used to some extent on harbor work. In Europe the ladder dredge is used for many excavating jobs.

The grapple dredge, equipped with either clam-shell or orange-peel bucket, is used principally in soft material where the depths

are great. It is used also, to some extent, for levee building where the material for the levees is taken from the river.

The hydraulic dredge, sometimes called suction dredge, has a wide use for excavating in soft material under water, and for filling in and reclaiming wet areas. Through its long discharge pipes it can deposit material at considerable distances. Sea-going hydraulic dredges, with hoppers in the hulls for holding the excavated materials until they can be dumped, are used to some extent in harbor work.

Some of the conditions which make for the economical use of the dredge on an excavating job are: (1) a large quantity of material to be moved, (2) material that is fairly homogeneous and free from solid rock, (3) ample depth and width of water for flotation and operation of the dredge, (4) a considerable amount of subaqueous digging.

THE FLOATING DIPPER DREDGE

Description.—The principal parts of the dipper dredge are the hull, the A-frame, the boom and dipper, the spuds, and the engines. As shown in Fig. 64, the A-frame, boom, and swinging mechanism are mounted at the forward end of the hull, with the boiler and main engines at the rear. The hull, which may be of wood or steel, is designed to float with as little draft as possible and yet to furnish ample support for the weight of the machinery and also provide for the severe stresses due to changing loads. Hulls are usually strengthened by trusses constructed inside. Wood hulls may be built on the job where the excavating is to be done.

A-frame.—The A-frame is composed of two or four legs, usually two, and may be made of wood or steel members. The feet are pinned to shoes on the deck of the hull or on the spud cross-framing. Wire rope back guys hold the A-frame to the hull. It is important that the A-frame be securely guyed and held rigid.

Spuds.—Most dipper dredges are equipped with three spuds, one on each side near the front of the hull and one at the center in the rear. Spuds are long, heavy timber or steel legs which can be raised and lowered. Their purpose is to steady the machine when digging and to aid in maneuvering it. Dredges operating in deep water or wide channels are equipped with vertical spuds which can be lowered to the bottom of the channel (see Fig. 64).

The vertical spuds are operated usually by independent engines or motors which drive drums on which the cables operating the



FIG. 64.—A 3-cu. yd. dipper dredge.

This machine is equipped with vertical spuds which are dropped to the bottom of the ditch. (Photo from Bull. 300, U. S. Dept. of Agr., Bureau of Public Roads.)

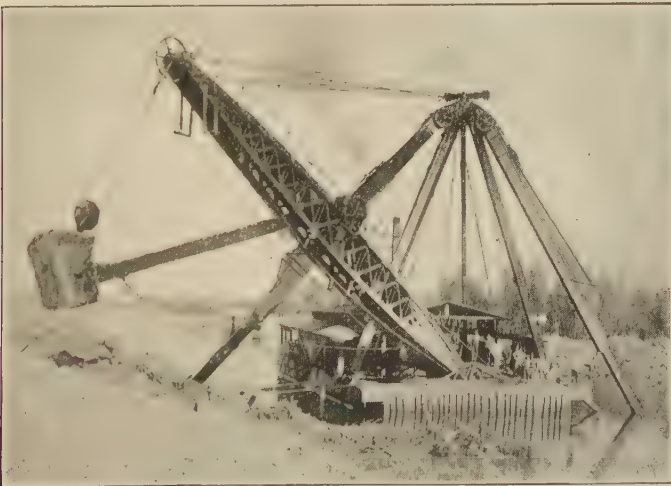


FIG. 65.—A 3½-cu. yd. dipper dredge equipped with telescopic bank spuds.

spuds can be wound. Machines designed for use in ditching and canal work have bank spuds at the front, and a vertical

spud at the rear. The bank spuds extend outward from the top of the A-frame and rest on the ground surface on each side of the dredge. These spuds have feet or bases of varying size according to the size of the dredge (see Fig. 65).

In operation, the forward spuds are used to raise up the forward end of the dredge a little (this is called "pinning up"), and



FIG. 66.—A Diesel-electric 10-cu. yd. dipper dredge.

Diesel engines are now being used on many large dredges for primary power. This dredge has a 1,200-hp. engine. (*Photo from Bucyrus Company.*)

the rear spud is used to keep the stern of the dredge from swinging as the dredge operates. When it is desired to move the machine ahead, the dipper is lowered to the bottom as far ahead as possible, then the forward spuds are raised and the backing rope is pulled. As the dredge moves forward, the stern spud leans forward with its point holding to the bottom and steadying the rear end of the boat. When the dredge is again in position to dig, the stern spud is raised until it assumes a vertical position and then it is lowered to the bottom.

The boom, dipper, and swinging mechanism of dipper dredges are quite similar in design and operation to the corresponding parts of the railroad-type steam shovel (see Chap. IV).

Power.—Dipper dredges may be operated by steam, electric, gasoline, or oil engines, though nearly all of them are steam operated. Recently electrically operated dipper dredges having Diesel engines for the primary power have been placed on the market (Fig. 66).

Dippers.—Dippers are of various sizes, ranging from $\frac{1}{2}$ - to 15-cu. yd. capacity. Machines used on ditching or canal work are equipped usually with dippers of from 1- to 5-cu. yd. capacity, while the largest dredges, such as those used on the Panama Canal, have 15-cu. yd. dippers.

Crew.—On small dipper dredges the work can be handled very well by four or five men—an operator, a cranesman, a fireman, and a deck hand or two. On the larger machines more men will be needed to handle the scows which carry away the excavated material and for general work around the dredge. On ditching work, where the material is dumped on the banks, of course, no scows are necessary.

Erection and Dismantling.—Dipper dredges used on ditch work are erected and dismantled on the job. When wood hulls are used, they are usually built at the time the dredge is to be assembled. Steel hulls are, of course, built at the factory, but they are made in sections which are assembled on the job. It is estimated that from 6 weeks to 2 months will be consumed by a force of 10 men completely to assemble a small dredge of $\frac{3}{4}$ - to $1\frac{1}{2}$ -yd. dipper capacity.¹ A somewhat longer time will be needed to erect the larger machines. Dismantling will take only about half as long as erection.

DIPPER-DREDGE METHODS AND PERFORMANCE

Ditch Construction.—Large drainage ditches are commonly dug by either some form of land machine, such as the dragline excavator, the dry-land dipper dredge or grab-bucket excavator, the wheel excavator, or the floating dipper dredge. No machine can equal the floating dipper dredge for constructing ditches of from 100 to 1,200 sq. ft. in cross-section through wet, timbered land, and this type is used more than any other for such work. The construction should always be started from the upper end, if

¹ *Bull.* 300, Bureau of Public Roads, U. S. Dept. of Agriculture.

at all possible. Otherwise it will be necessary to build dams below the machine to maintain flotation for it. To operate economically the dredge hull should float as high as possible. This makes it possible for the dipper to utilize its full capacity and dump the material as far as the reach of the boom will permit. Best operation is secured, therefore, when the ditch is nearly full of water, and the exposed face does not exceed about 2 ft.

When the tract to be ditched is heavily timbered, the trees should be removed and the logs cut into such lengths that they can be handled when the dredge comes along. A dipper dredge can dig out stumps, but time spent at such work reduces the output. It is therefore advisable to loosen the stumps by blasting.

The usual method of handling a ditch job is to complete the cut as the machine progresses. On very wide ditches pilot cuts are often made along the sides of the ditch and the center section is removed later.

For a given job, once the cross-section of the proposed ditch and the elevation to which the water in the ditch can be maintained are known, the proper size of dredge can be selected. A hull can be designed of such dimensions and draft that it can operate in the ditch, and then the length of boom and size of dipper can be determined.

For small ditches a $1\frac{1}{2}$ -yd. dredge is recommended. This machine, with a 40- to 50-ft. boom, can be mounted on a fairly light hull which will not require much depth for flotation. On jobs where the cross-section of the proposed ditch is large enough to accommodate a larger hull, the $2\frac{1}{2}$ - to 3-yd. dredge will be found economical. In all cases, it is well to use a hull of such dimensions that it will just comfortably clear the sides of the ditch.

Table XIII, which was compiled from data given in *Bulletin* 300, Bureau of Public Roads, U. S. Dept. of Agriculture, indicates for each size of dredge the minimum economical yardage, the average output under continuous operation, and the average coal consumption per shift.

The width of the hull is generally about one-half the length of the boom for bank spud dredges and about five-eighths the length of the boom for dredges with vertical spuds. The dipper handle is ordinarily about two-thirds the length of the boom. These dimensions, however, should be worked out for each job.

TABLE XIII.—AVERAGE OUTPUTS AND COAL CONSUMPTION OF DIPPER DREDGES

Size of dipper, cubic yards	Usual length of boom, feet	Minimum economical yardage, cubic yards	Average out- put per month (52 shifts), cubic yards	Average coal consumption per shift, tons
$\frac{3}{4}$	30	100,000	20,000	$1\frac{1}{2}$
1	40	300,000	27,000	2
$1\frac{1}{2}$	50	500,000	37,000	3
2	55	800,000	47,000	$3\frac{1}{2}$
$2\frac{1}{2}$	65	1,000,000	55,000	$3\frac{3}{4}$
3	80	1,500,000	70,000	4
$3\frac{1}{2}$	80	2,000,000	75,000	$4\frac{3}{4}$
$4\frac{1}{4}$	90	3,000,000	80,000	6

In general, dipper dredges with vertical spuds will dig to advantage through an arc of 90 deg.—that is, at an angle of 45 deg. each side of straight ahead. Dredges have worked at much greater angles than this, but such work puts a very heavy strain on the machine.

The width of bottom that can be excavated without shifting the dredge will be a little over 60 per cent of the length of the boom. Bank-spud machines may exceed this figure somewhat.

Typical Ditching Operations.—Several ditching jobs which were handled by floating dipper dredges are described in the bulletin referred to above. Some of these records are abstracted below.

In North Carolina a ditch $9\frac{1}{2}$ miles long, and averaging from 22 to 30 ft. wide on top and from 8 to 10 ft. in depth, was constructed by a floating dipper dredge. The water level here was easily maintained near the original ground level and very little clearing had to be done. The material was clay and muck. The dredge used was mounted on a 20- by 70-ft. hull, with a draft of 5-ft., and was equipped with $1\frac{1}{4}$ -yd. dipper on a 31-ft. dipper handle and 45-ft. boom. It had convertible forward spuds which could be used either as bank or vertical spuds. This machine was operated by a crew of 5 or 6 men, who were paid at the following rates: superintendent, \$110 per month; engineer, \$100 per month; cranesman, \$60 per month; fireman, \$48 per month; deck hands, \$36 per month. As the dredge operated practically

continuously (in two 11-hr. shifts), two crews were needed. In one year of operation 350,720 cu. yd. of earth was excavated by this machine at a cost of about 6 cts. per cubic yard. This cost does not include the original cost of the dredge, but does include interest at 6 per cent on the investment and depreciation at 35 per cent per year. The initial cost of the dredge was \$10,342.

On a job in Colorado, 20 miles of canal was cleaned out and enlarged by a 1½-yd. dipper dredge mounted on a 24- by 75-ft. hull, which had a 50-ft. boom. No clearing was necessary on this project. The dredge was operated on two 11-hr. shifts per day. During a year it was actually working 187 days, and in this time 394,387 cu. yd. of earth was removed, according to measurements of the theoretical cross-section. It is probable that the actual amount excavated was around 25 per cent more than the above figure. The crew on this dredge consisted of one head runner at \$120 per month; one runner at \$110 per month; two cranesmen at \$55 per month each; two firemen at \$45 per month each; two deck hands at \$40 per month each; one teamster at \$40 per month; and one cook at \$50 per month. Board was furnished. The cost of this job was:

Labor operating dredge.....	\$ 6,243.70
Coal, 1276.65 tons at \$2.35.....	3,000.13
Hauling coal.....	1,053.24
Oil, waste, and supplies.....	692.80
Cost of controlling water to float dredge.....	369.24
Repairs (labor and materials).....	3,894.67
Removing and replacing bridges.....	837.78
Interest and depreciation.....	6,765.00
Total.....	\$22,856.56

This gives a unit cost of \$0.058 per cubic yard.

Additional expenses of \$6,768.27 included engineering and supervision, and the cost of building up the ditch bank and making a road on top of it. The cost of the dredge, ready to work, was \$16,500.

In Louisiana a ditch was dug by a 1¼-yd. dipper dredge mounted on a 5- by 22- by 73-ft. hull, with a 40-ft. boom and bank spuds. This ditch averaged 30 ft. in width and 5 to 6 ft. deep. The land was nearly level and the water level was easily kept near the ground surface. The material was muck underlain with alluvial mud which was very soft. There were

no stumps or logs to move. The machine operated for 2 yr. on this job, on 12-hr. shifts. The average output per shift was 1,200 cu. yd. on a section 30 ft. wide on top and 5 ft. deep. A crew of four men operated the dredge.

Drainage of the Roseau River swamp in northern Minnesota was accomplished by dredging the channel of the Roseau River for 36 miles and constructing lateral ditches; cut-off channels were dug at some places. The improved channels had 60-ft. bottoms, with side slopes of 1 to 1. The work on a 17-mile stretch of this channel involved the removal of 450,000 cu. yd. of earth and 84,000 cu. yd. of hardpan. For this work a dipper dredge on a 40- by 90-ft. hull was used; it had a 72-ft. boom and 2-yd. dipper. Vertical spuds were used. The excavated material was wasted on both banks, leaving an 8-ft. berm. The maximum monthly output, working two 10-hr. shifts per day, was 80,000 cu. yd. The contract price for this work was 10 cts. per cubic yard for earth and 25 cts. per cubic yard for rock excavation (1914-1915).¹

On a reclamation and drainage project in Louisiana near Lake Pontchartrain, a 3½-yd. dipper dredge was used for part of the work. This machine was mounted on a steel hull 137½ by 38½ by 9 ft. deep, equipped with vertical spuds. Its principal work was to dig a muck ditch 40 ft. wide on top and averaging 6 ft. in depth. The excavated material was thrown up on both sides to form retaining levees. The space between these levees was later filled with material pumped by a hydraulic dredge. During 1 month the dipper dredge dug 5 miles of ditch through light marsh land with no stumps. Operation was practically continuous. According to estimates, the quantity moved in this month was 180,600 cu. yd.²

On the Little River Drainage District, in Missouri, 600 miles of ditches were constructed by 26 dipper dredges of various sizes. The smaller ones had 1-yd. dippers and bank spuds; the largest had 4-yd. dippers and vertical spuds. On the main ditches the 1-yd. dredges made two pilot cuts 6 ft. deep, one on each side of the proposed ditch. These cuts were about 22 ft. wide on top and 12 ft. on the bottom, with 1 to 1 side slopes on the outer side. A larger dredge extended each pilot cut to the full depth of 8 to 12 ft., and then took out the center section. On the largest ditch, which had a bottom width of 123 ft., a 4-yd.

¹ *Engineering News*, Vol. 75, No. 8.

² *Excavating Eng.*, September 1925.

TABLE XIV.—OUTPUT OF DIPPER DREDGES ON DRAINAGE DISTRICT No. 9,
MISSISSIPPI COUNTY, ARKANSAS

Dates	1¼-yd. dipper, 50-ft. boom	1½-yd. dipper, 45-ft. boom	2-yd. dipper, 45-ft. boom	4½-yd. dipper, 75-ft. boom	4½-yd. dipper, 85-ft. boom
September 1912.....		30,114	32,148		
October.....		41,308	38,778		
November.....		56,131	29,179		
December 1912.....		48,310	20,066		
January 1913.....		30,264	53,771		
February.....		37,854	42,698		
March.....	31,315	56,774	40,323		
April.....	30,311	42,812	22,784		
May.....	12,226	23,027	30,004	84,241	
June.....	20,714	52,162	22,611	81,376	
July.....	20,670	48,888	25,309	38,175	
August.....		35,475	37,172	67,326	
September.....		26,889	31,172	74,320	
October.....		34,592			94,205
November.....		33,625	30,253		95,000
December 1913.....		41,518			52,872
January 1914.....		34,974	23,421	80,372	89,914
February.....	12,102	35,367	20,602	86,164	73,244
March.....	20,193	49,746	17,414	40,952	
April.....	20,950	29,550	29,980	121,666	72,673
May.....	18,685		47,094	67,773	53,114
June.....	27,733	36,205	26,880	48,928	79,835
July.....	27,212	19,020	29,219	43,413	95,794
August.....		37,356		84,305	74,866
September.....		26,633		84,431	81,475
October.....		24,433		73,209	85,955
November.....		23,492		64,445	89,841
December 1914.....		31,210		90,696	
January 1915.....			33,600	77,324	112,861
February.....	31,589		26,003	49,204	83,023
March.....	26,047	35,200	36,789	107,137	100,534
April.....	18,633	25,455	47,825	74,951	115,529
May.....	19,846	28,222	39,307	64,237	75,962
June.....	24,717	27,828	26,553	123,029	95,463
July.....	20,726	32,289	39,270	67,825	69,230
August.....	20,026	33,520	38,735	98,765	79,089
September.....	18,659			62,075	
Total.....	422,354	1,170,243	938,960	1,956,339	1,770,479
Average per month..	22,830	35,462	32,378	78,254	84,308
Average per hour....	44	68	62	150	162

dredge took out 83,278 cu. yd. in 26 days of two 12-hr. shifts. The 1 to 1 side slopes were obtained by taking out a succession of light cuts on each side in such a manner as to approximate the 1 to 1 slope with the final cut.¹

Table XIV shows the amount of work done over a considerable period and the average output per month for several dipper dredges of various sizes on Drainage District No. 9, Mississippi County, Arkansas. Months or parts of months have been omitted during which there was not sufficient water to operate, or when the dredges were required to remain idle on account of conditions entirely beyond the control of the contractors. Time spent on repairs was not deducted. All the dredges operated an equivalent of two 10-hr. shifts per day, and for convenience the monthly averages have been reduced to hourly averages by dividing by 520. All of the quantities given are based on "pay" excavation. The actual amounts excavated were somewhat greater,—at least 10 per cent more for the smaller dredges.

Large Dipper Dredges.—Some very large floating dipper dredges have been used, and are now in use, for large-scale subaqueous excavation operations. On the Great Lakes, in New England, and around New York harbor, and especially on the Panama Canal, these dredges have been used to great advantage to remove large quantities of material in the minimum time.

In "Dredges and Dredging," Charles Prelini describes the dipper dredge "Majestic," which was built for use on channel work in the St. Mary's River, Michigan. This machine had power enough to dredge solid beds of soft limestone without blasting. It had a steel hull, 116 by 40 ft. by 13 ft. deep, and was equipped with a 60-ft. boom and 6- or 8-yd. dipper. When working in rock the 6-yd. dipper was used, and the estimated capacity was from 40 to 50 cu. yd. per hour. In softer material, using the 8-yd. dipper, the capacity was from 400 to 500 cu. yd. per hour.

Excavation of the Cape Cod canal in Massachusetts was handled by two 10-yd. dipper dredges, each on steel hulls 130 by 42 ft. by 10 ft. deep. The dipper handles were 70 ft. long. During one season, working continuously in three 8-hr. shifts per day, the average monthly output of these machines was 100,000 cu. yd. each. The material handled was mostly sand.²

¹ *Eng. News*, Vol. 76, No. 16.

² *Eng. News*, Feb. 19, 1914.

On the Panama Canal three 15-yd. dipper dredges were built for use in excavating the Gaillard Cut, which was largely a rock excavation. Later these dredges were used in removing various slides. The "Gamboa," one of these dredges, had a hull 144 by 44 ft. by 13½ ft. deep. It could dig 50 ft. below the water level. Equipped with a 15-yd. dipper, this machine removed 15,425 cu. yd. of rock and earth in 21 hr. actual digging time, and averaged 12,828 cu. yd. per day for 10 days. It operated continuously in three 8-hr. shifts. The "Cascadas," a similar dredge, dug 1,447,946 cu. yd. at an average hourly rate of 466 cu. yd. per hour over a working period of about 3,104 hr.¹

Perhaps the largest and most powerful dipper dredge operating at present is the dredge "Crest" which is being used for the removal of blasted rock in New York harbor. This dredge is mounted on a hull 167 by 48 ft., and uses either a 10- or 15-cu. yd. dipper. It has a dipper pull of 350,000 lb. The motive power is a Diesel-electric combination, two 600-hp. Diesel oil-burning engines driving direct-current generators. Seven main motors are used for the thrust, hoist, backing, swing, and spud machinery. The spuds are 85 ft. long and 51 in. square. This machine can dig to a depth of 52 ft.²

THE DRY-LAND DIPPER DREDGE

On certain ditching projects sufficient water is not available for flotation of a dipper dredge mounted on a hull, or the cross-section of the proposed ditches is not large enough to accommodate a floating hull. To meet these conditions various excavating machines have been devised. One of these is the dry land dipper dredge—a machine which operates in the same manner as the floating dredge; except that the steel or timber supporting frame is mounted on skids or trucks which rest on the banks of the ditch. Naturally, such machines are limited to use on the narrower ditches. Generally the limits of span for these machines are from 12 to 40 ft. They are usually equipped with ½ or 1-yd. dippers, and booms of from 20- to 45-ft. lengths, and are either truck mounted or furnished with a so-called "walking device," which requires no tracking. These machines can be assembled and dismantled very easily and quickly (see Fig. 67).

¹ *Excavating Eng.*, June 1924.

² *Eng. Contr.*, January 1927.

The power is usually furnished by gasoline or oil engines.

The track machines require a crew of three men—one operator and two trackmen. A two-man crew—operator and helper—can handle the walking type. The latter type has a “walking speed” of about 500 to 800 ft. per hour. These machines, in ordinary digging, can average about 500 cu. yd. per 10-hr. shift.

Since the development of the dragline excavator in recent years to include small machines of the walking type or with caterpillar traction, it is usually possible to use a machine of this type on ditch work where the ground is firm enough to support it. Such a machine, in many cases, is more economical and more easily handled than the dry-land dipper dredge.



FIG. 67.—Walking dry-land dipper dredge.

These machines are often used in ditching operations where the cuts are narrow enough to be spanned by the dredges. (*Photo from Bull. 300, U. S. Dept. of Agri., Bureau of Public Roads.*)

THE HYDRAULIC DREDGE

Description.—The hydraulic dredge is of simple construction. It consists essentially of a floating hull upon which is mounted a centrifugal pump which lifts the mixture of solids and water from the channel bottom through a suction pipe and pumps it through a discharge pipe of varying length to the place of deposition. Most of the seagoing hydraulic dredges are self-propelled and usually have hoppers built into the hulls to hold temporarily the excavated material. Hydraulic dredges for river-channel and harbor work may be either self-propelled or of the more usual non-propelling type. They are sometimes classified according to the design and location of the suction feed into three types:

(1) lateral feeding, (2) forward feeding, and (3) radial feeding. The latter two types are more common for general channel use, and will be described in some detail (see Fig. 68).

Suction Feed.—The suction tube is made up of sections of wrought-iron or steel pipe from 10 to 30 in. in diameter, according to the size of the pump. This suction pipe is attached to a ladder or steel frame, usually of the plate-girder type, which is wider at the top than at the suction or lower end (see Fig. 69). At the lower end of the ladder the suction head is fastened. This



FIG. 68.—A 20-in. hydraulic dredge.

Machines of this size are commonly used on large scale hydraulic dredge work.
(Photo from Bucyrus Company.)

head should be designed so as to place the suction inlet within the cutter head. The upper end of the ladder is hinged by trunnions in a shallow well in the center of the bow of the hull. If the dredge is of the forward-feeding type—that is, of such construction that the entire hull is swung about in reaching for material—the ladder need have motion only in a vertical plane. On dredges of the radial-feeding type, the joint of the ladder to the hull must be designed to permit horizontal as well as vertical motion of the ladder. The ladder can be raised or lowered by wire ropes running over sheaves at the top of the boom or jib

frame. The latter is usually inclined forward at an angle of about 45 deg. and is guyed by back guys to the A-frame.

The movable part of the suction pipe is joined to the intake pipe of the pump by a rubber sleeve or a metal ball joint, the

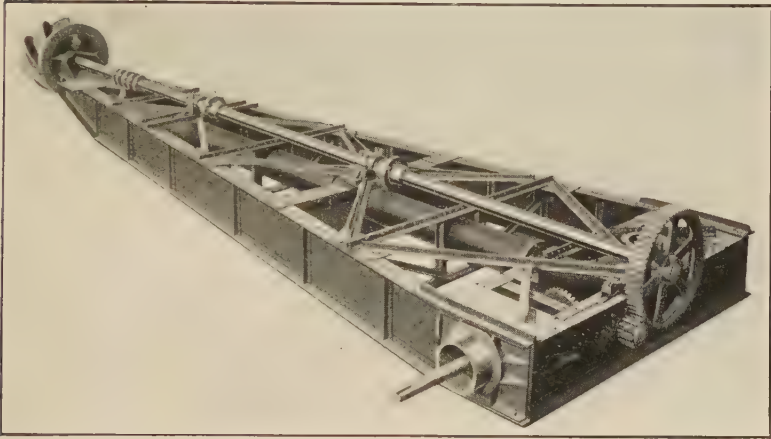


FIG. 69.—Digging ladder for 20-in. hydraulic dredge.

The shaft which operates the cutter head rides on top of the ladder. The suction pipe is just below the shaft. (*Photo from Bucyrus Company.*)

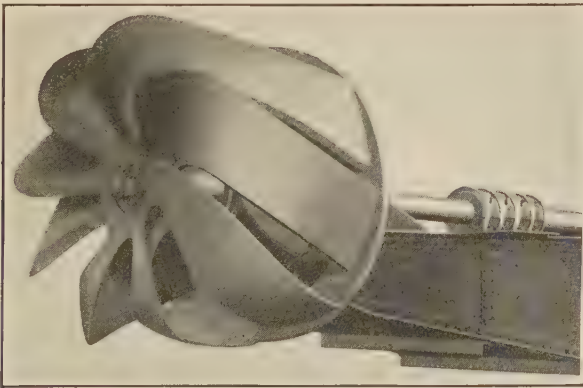


FIG. 70.—An eight-blade cutter head for hydraulic dredge.

This is a heavy cutter head especially designed for hard digging. (*Photo from Bucyrus Company.*)

latter connection being more common on the large dredges. In operation the ladder is usually suspended at an angle of 45 deg. or less with the vertical.

Cutter Head.—To assist in loosening the material to be dug, the lower end of the suction pipe is equipped with some type of agitator or cutter head, unless a water jet is used to stir up the material. In very soft material the attachment to the suction pipe may be simply a scraper; in harder material it consists of a set of revolving blades which actually cut or slice into the material. This cutter head is rotated by a shaft fastened to the ladder above the suction pipe and geared at the upper end to either the main or an auxiliary engine. Cutter heads are much larger in diameter than the suction pipe; on the large dredges they are 6-ft. in diameter and have from five to eight blades (see Fig. 70).

In loose-sand excavation a water jet instead of a cutter head is often used to stir up the material. The jet pipe is laid close to the suction pipe, so that the nozzle will act on the material directly under the suction head. Pressure for the jet may be obtained either from the main pump or a small independent jet pump.

Spuds.—Most forward-feeding dredges with non-radial ladders have two vertical spuds set near the stern of the hull, one on each side. The spuds are raised by winches and dropped by gravity; they are made either of heavy timbers or of metal. When the dredge is working, one of these spuds is up and the other is in the bottom, so that the dredge can pivot about the spud that is down. When it is desired to move ahead, the high spud is dropped and the low one is raised, while the dredge is over to one side of the cut; then the dredge swings about the spud that is down. Thus the machine can be moved ahead in zigzag fashion.

Many dredges of the radial-feeding type have three or four vertical spuds, all of which are down while the dredge is digging. These spuds are mounted so that they can be inclined when down, and motion ahead is accomplished by pulling on the forward spuds by means of wires attached near their bases and extending over sheaves on the stern of the hull to a winding drum. This inclines the forward spuds, which can be raised and plumbed after the dredge is in position for further digging.

When a hydraulic dredge is working in a narrow channel, as in ditching work, it is often moved ahead by cables operated by a hoisting engine and attached to deadmen along the banks.

Pumps.—The pumps used on hydraulic dredges are of the single-stage, high-pressure centrifugal type, designed especially for the kind of work they must perform. Pump shells and run-

ners, as well as the pipe lines, suffer considerable wear due to abrasion of the solids carried through; this wear is very severe when the dredge operates in gravelly material. Modern practice in dredge-pump design is to make the pump shells and runners of specially prepared steel, such as manganese or nickel-chrome steel, or of cast iron of a special type. Removable and renewable shoes on the vanes of the runners are often used; these are attached to the vanes by bolts and can be replaced when worn down.

As explained more fully in Chap. XIII, experiments made by engineers of the Miami Conservancy District in cooperation with the manufacturers, developed a very serviceable pump shell of special white iron. These shells were good for as much as five times the yardage that was handled by ordinary cast-iron shells, and gave as good service as the more expensive manganese steel shells, on a pound for pound basis. The white-iron shells were made much thicker than the usual steel shells and had extra thickness at the points of greatest wear, thus making it possible to get longer life from the shells at a saving in cost. It is not practical to make the manganese steel shells more than about $2\frac{3}{4}$ in. in thickness, due to shrinkage stresses in the metal during the process of casting. However, manganese steel runners were used with the white-iron shells, as the latter material was not satisfactory for the runners.

Dredge pumps should be designed so that the openings between the vanes of the runners are large enough to pass such material as can pass through the cutter and suction heads. For this reason these pumps do not have high efficiency—about 50 per cent efficiency is the best that can be expected.

The function of the pump is to produce a suction in the intake or suction pipe so as to lift the material and then to produce sufficient pressure to force the material through the discharge pipe to the point of discharge. Therefore pumps must be designed to overcome the suction head, the elevation or static head, which is the height the material is raised, and the friction head in the pump and pipe line, taking into consideration that a considerable amount of solids are to be pumped with the water. The friction head is affected by the character and percentage of solids; it is directly proportional to the length of the pipe line; it increases with an increase in the velocity of discharge and decreases with an increase in the diameter of the discharge pipe.

The main dredge pump is usually mounted on or near the long axis of the hull as close as practicable to the front end. The pump shaft is direct-connected or belt-connected to the power plant. Often a small auxiliary centrifugal pump is used for priming the main pump. Priming is accomplished as follows: First the valve in the discharge line is closed and the suction pipe is raised until its end is higher than the pump, then water is pumped into the main pump until the priming water discharges from the end of the suction pipe; then the suction pipe is dropped and the dredge pump is started, after the discharge line valve has been opened.



FIG. 71.—A 24-in. electric hydraulic dredge.

The revolving screen in the center of the hull rejects all oversize material and dumps it back into the stream. (*Photo from Bucyrus Company.*)

The size of the pump used on a dredge determines the output. The usual sizes range from 10 to 24 in., and the 20-in. pump is largely used for dredge work of any magnitude.

The sizes mentioned refer to the diameter of the suction and discharge pipes. Pump runners or impellers should have at least a diameter of about two and a half times the diameter of the pipe, for efficient operation.

Power.—Hydraulic dredges are operated by either steam or electric power (see Fig. 71), though steam operation is more common at the present time. The main engine is usually a

vertical compound or triple expansion engine of the marine type. Ordinarily it is direct-connected to and mounted on the same subbase with the pump. Separate small engines are commonly used for operating the winches for the spud hoists and for the cutter head drive.

To determine the amount of power required to operate the dredge pump the following factors must be considered: (1) diameter of the suction and discharge pipes, (2) length and kind of discharge pipe, (3) character of end connections, (4) static or elevation head, (5) efficiency of the pump and engine, (6) nature of material, and (7) percentage of solids to be transported. The following table, taken from *Bulletin* 300, U. S. Department of Agriculture, gives the capacities and required power for dredges ranging in size from 4 to 24 in.

TABLE XV.—CAPACITIES AND REQUIRED POWER FOR HYDRAULIC DREDGES

Diameter of suction and discharge pipe, inches	Normal capacity, gallons per minute	Solids pumped per hour, cubic yards, per cent			Approximate horsepower required for each foot of total head
		10	15	20	
4	450	12	18	24	0.4
5	700	20	30	40	0.6
6	1,000	30	45	60	0.8
8	1,800	50	75	100	1.5
10	2,800	90	135	180	2.5
12	4,000	130	195	260	3.0
15	6,300	200	300	400	5.0
18	9,000	300	450	600	7.0
20	13,000	375	560	750	8.0
24	17,000	500	750	1,000	10.0

Discharge Pipe.—The discharge pipe, which is the same size as the suction pipe, is made up of sections of wrought iron or steel pipe, usually with either stovepipe or flanged joints. The lengths of pipe may vary, but 14- to 20-ft. lengths are commonly used, except for the part of the line which may be supported on pontoons, where longer sections of pipe are better. The discharge line is connected to the fixed discharge pipe at the stern of the dredge hull by a ball joint, or sometimes by a slip joint. At the joints in the discharge line, the pipes may be held together by loops of wire wound around projecting lugs near

the end of each length. The usual pipe material is No. 8 or No. 10 gage stock, of riveted or welded steel. A high-carbon electrically welded steel pipe was developed in connection with the Miami Conservancy District work which proved very satisfactory, as it gave service about three times as great as the mild steel dredge pipe and cost no more. The material on that job had a large gravel content, and pipe wear was a major factor. Further details regarding this pipe may be found in Chap. XIII.

It is common practice to turn the pipe about one-third the way around at certain intervals to insure even wear and get the maximum life from the pipe, as the greatest wear is along the bottom.

The portion of the discharge line extending from the dredge to the shore is supported on pontoons of suitable construction. Each pontoon carries a section of pipe varying in length from about 20 to 60 ft. The shore-discharge line may be supported on trestles or may be laid on the ground. The last section or two of the shore pipe sometimes is provided with "window valves" or openings in the bottom of the pipe at intervals so that part of the solids will drop out as the material passes through.

HYDRAULIC-DREDGE OPERATION

As stated before, the hydraulic dredge is used principally for widening, deepening and maintaining large ditches, canals, rivers, or harbors, or for constructing new channels, ditches or canals where the material to be excavated is mud, silt, clay, or small gravel containing no large or solid rock, of a fairly homogeneous nature, and is not obstructed by stumps or large debris; and for reclaiming wet or low areas by filling, usually with sandy material. A second necessary condition for hydraulic-dredge work is that there be within a reasonable distance a spoil area for the excavated material.

It is considered that the maximum distance which the dredged material can be economically pumped is about 5,000 ft., unless booster pumps are used in the discharge line. Since the capacity of the dredge depends very largely on the length of the discharge line, it is well to keep the dredge as close as possible to the spoil area. To minimize friction losses, it is good practice to keep the

discharge line carefully lined up, and to avoid bends and elbows as much as possible.

Hydraulic dredges may be designed to dig to depths as great as 100 ft., which is about twice the maximum depth to which dipper dredges can operate. Of course, the greater the depth, the longer the suction pipe must be, and in this connection it should be remembered that the suction pipe is usually held to an angle of 45 deg. or less for most effective work.

To secure consistent and satisfactory outputs on hydraulic-dredging work, it is absolutely essential that experienced and careful operators be employed. A dredge pump will handle water more easily than a mixture of solids and water, and it requires constant attention and some skill to so manipulate the suction head as to obtain the best percentage of solids. The difficulty is that the material is out of sight below water. The operator has before him a vacuum gage which indicates the amount of vacuum in the suction line, and a pressure gage attached to the discharge pipe. The latter gage indicates the sum of the elevation and friction heads. Both gages can be calibrated to read in feet of head, though usually the vacuum gage reads in inches of mercury (barometric scale) and the pressure gage reads in pounds per square inch. To convert the vacuum-gage readings into feet of head, multiply the reading by 1.13. To convert the pressure-gage readings into feet of head, multiply the reading by 2.304.

The operator can tell from the vacuum-gage readings when the pump is handling the proper amount of solids, as the vacuum is greater when pumping solids and water than it is when pumping water alone. Ordinarily the total suction head should not exceed 25 ft. Pressure-gage readings vary with the length of discharge pipe and the elevation to which the material is being pumped. The maximum discharge pressure for the usual sizes of pumps should be from 45 to 55 lb. per square inch. Obstructions in the suction line cause a drop in the discharge pressure, and obstructions in the discharge line cause an increase in the discharge pressure. Plugs in the pipe lines are a chief source of trouble in dredging operations, and must be carefully guarded against, as a plug in either the suction or discharge line means a considerable delay while the pipes are being taken out and cleaned. Incipient plugs can often be detected from observations of the gages in time to avert trouble. By alternately speeding up and

slowing down the pump the material usually can be cleared out. Maximum output is secured when the discharge line is loaded almost to the point of plugging.

Pumps on hydraulic dredges that are used for digging different kinds of materials with varying lengths of discharge lines should have several runners of various sizes which can be interchanged where necessary in order to keep up the efficiency of the pumps. If removable shoes are used on the runners, these shoes can be of different lengths. On the Miami Conservancy District work, where 15-in. pumps were used, 36- and 42-in. runners were interchanged. Shoes for the 36-in. runners were 36-, 38- and 40-in. size, and on the 42-in. runners, 42-, 44- and 46-in. shoes were used. Thus the efficiency of the pumps could be maintained with heads varying from 25 to 150 ft.

The percentage of solids pumped will vary. In mud or silt 20 per cent or more solids may be handled, while in sand and gravel the usual amount is about 10 per cent. For light material which is easily carried in suspension large-diameter pipe with a low-discharge velocity may be used; for heavier material, such as gravel, a smaller pipe with a higher velocity will be necessary. The smaller the diameter of the discharge pipe the higher will be the velocity for a given discharge, and the greater will be the possible percentage of solids.

The width of cut made by a hydraulic dredge depends upon the type of machine. A radial feeding dredge will make a cut a little wider than the hull width, while the swinging dredge will have to work in a much wider cut, as it must have room to swing about its spuds in order to move ahead. Where the forward movement is secured by pulling on anchor lines, the cut need be only wide enough to pass the hull.

Hydraulic dredges can handle a bank above water by undercutting it and allowing it to cave in. In some cases hydraulic monitors are mounted on the dredge hull to sluice down banks which will not easily cave.

The crew for a hydraulic dredge will consist of the following men for each shift: one operator, one engineer, one oiler, one fireman, and several deck hands or coal passers. On the shore enough men will be needed to look after the pipe lines.

On the St. John Levee and Drainage District, in Missouri, a hydraulic dredge was used to build a levee of sandy material about a mile long. The material was taken from the river and

a borrow pit about 30 to 40 ft. deep. The maximum length of discharge line was 1,500 ft. The dredge had a 10-in. pump mounted on a small hull. The discharge pipe was made up of 18-ft. lengths of spiral riveted steel pipe. On this job the average output was 1,000 cu. yd. in a 12-hr. shift. The discharge contained about 10 per cent solid matter.¹

A large fill was made at Waukegan, Ill., for a factory site. All of the material, which was lake sand, was pumped by a hydraulic dredge. A channel 250 ft. wide and 4,200 ft. long parallel to one side of the tract to be filled was dredged to furnish the material, which was distributed to a depth of from 6 to 16 ft. over an area of about 65 acres. The dredging outfit was a 15-in. vertical pump electrically operated by a 600-kw. motor at 440 r.p.m. A separate jet pump, with an 8-in. suction and 6-in. discharge, was used to assist in stirring up the material instead of a cutter head. A discharge pipe from this jet pump was connected into the discharge line of the main pump for the purpose of aiding in the removal of plugs in the line. The main discharge line was laid horizontal to the edge of the channel and then turned upward in one lift to the main pipe line mounted on a trestle paralleling the channel. All pipe lines were laid on trestles and were kept true to line and grade, with descending grades from the main line to the discharge ends of all laterals. The greatest length of discharge pipe was 4,700 ft.

Plugs were cleared by raising the suction line, stopping the main pump, then draining the discharge line into the pit. Then the jet pump would pump into the discharge line, causing a pond to form behind the plug, which never extended to the top of the pipe, partly due to the incline of the pipe. As the pondage increased the additional pressure gradually eroded an opening in the plug and washed out a channel through it. Then the main pump was started, pumping clear water, and took out the remainder of the plug.

The average proportion of solids pumped on this job was $12\frac{1}{2}$ per cent, though at times as high as 27 per cent solids were pumped.²

THE LADDER DREDGE

The ladder or elevator dredge has for its digging mechanism a series of buckets attached to two endless chains or conveyors

¹ *Eng. News*, Vol. 76, No. 4.

² *Eng. News Record*, Vol. 85, No. 17.

which run along a ladder frame and revolve around drums or tumblers at the ends of the ladder. One end of the ladder is fixed to a tower on the hull near the front, and the other is suspended from a heavy frame or gantry built of timber or steel. The buckets dump into a chute at the top of the ladder which drops the material into hoppers or onto barges, or sometimes the buckets deposit material onto belt conveyors.

The digging buckets are made of steel and vary in size from 7 to 13 cu. ft. for use in rock or hard digging, and from $\frac{1}{2}$ to 1

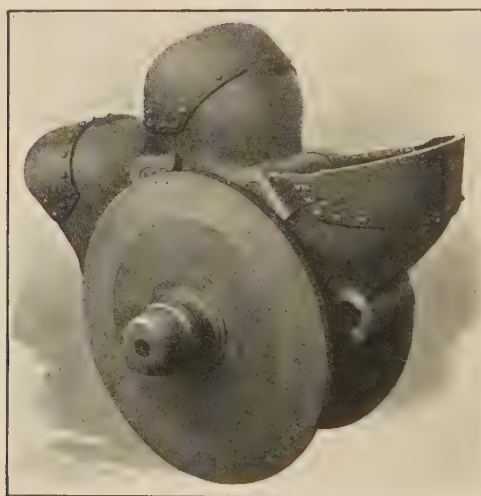


FIG. 72.—Lower tumbler with buckets.

The tumbler at the lower end of the ladder is a single-piece steel casting with a cylindrical barrel and circular flanges. (*Photo from Bucyrus Company.*)

cu. yd. for use in soft material (see Fig. 72). When the dredge is to be used in different classes of material it is usually equipped with two sets of buckets, one for digging in soft material and one for heavy work. The chains of buckets are either close connected or open connected. Close-connected buckets are fastened directly together while the open-connected chain has links between the buckets. For placer-mining work the close-connected chain of buckets is always used.

The ladder, which is made up of structural members, usually girders, is raised and lowered by chains extending from the lower end to blocks on the gantry and the power is furnished by reversible engines connected to drums. The upper side of the

ladder is provided with rollers over which the loaded buckets pass as they ascend (Fig. 73).

The tower to which the upper end of the ladder is fastened is usually from 20 to 25 ft. high, though one type of ladder dredge, known as the "high-tower" type, has towers from 75 to 80 ft. in height.

Ladder dredges are mounted on either stationary or self-propelled hulls. The seagoing types are, of course, self-propelled. Those used for river or harbor work are moved by pulling on anchor lines, sometimes assisted by "walking" spuds such as are used on hydraulic dredges.

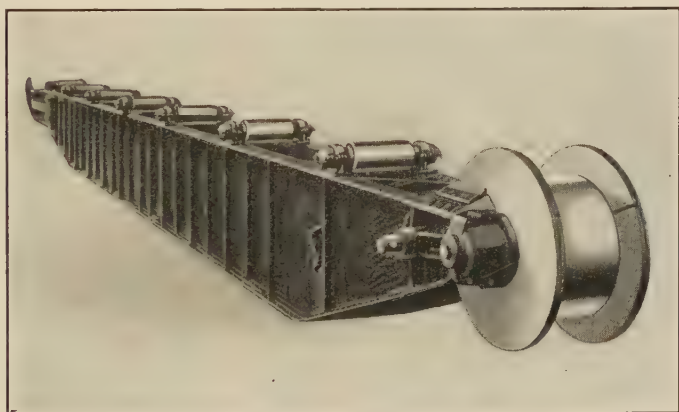


FIG. 73.—Standard-type digging ladder.

Ladders are usually constructed from plate girders tied together with cross-bracing and plates. The buckets are carried over the rollers shown on top of the ladder. (*Photo from Bucyrus Company.*)

LADDER DREDGE OPERATION

The ladder dredge is used in this country in placer mining, for sand and gravel digging, and to some extent for channel and harbor work. This type of excavator is the only dredge that can dig a smooth bottom. Other advantages are its continuous operation and large capacity. However, it has many moving parts, is costly to build, and there is much wear in the moving parts, many of which are under water. It can dig deeper than the dipper dredge, and, where the material is too hard for hydraulic dredges to work, can be used to advantage on deep excavation.

The dredge operates by swinging back and forth across the cut, taking out a layer at each swing. The effective digging depth of the buckets is the distance between the cutting edge and the overlapping flange of the lower tumbler. Most of the digging is done by the sides of the buckets.

The elevated material is dumped into a hopper or into chutes leading to scows alongside the dredge. Sometimes two chutes are used so that scows may be loaded on each side of the dredge. The high-tower dredges are designed to chute the excavated material directly to the bank on one or both sides of the dredge. Such a dredge is useful chiefly on narrow channel excavations.

When the excavated material is dumped onto belt conveyors and transported thence to the shore or to scows, attention must be given to the pitch or slope of the conveyors. Soft, wet material will flow easily and the belt cannot be inclined much; if the material is gravelly a greater slope may be taken.

Placer dredges (see Fig. 74), working metal-bearing materials, dump the worked-over material back into the channel behind the dredge after the metal has been recovered by screening and other processes on the dredge.

Clay has a tendency to stick in the buckets, and a ladder dredge cannot operate as fast in clay as it can in less sticky materials. In sand or gravel the dredge can be operated at a speed of about 20 buckets per minute. The efficiency of the dredge will depend on the nature of the material and the capacity of the buckets.

The Iron City Sand and Gravel Company, of Pittsburgh, operates a large Diesel-electric ladder dredge. The digging mechanism consists of a chain of close-connected 8-cu. ft. buckets mounted on a 95-ft. steel ladder, with a maximum digging depth of 50 ft. A 300-hp. diesel oil engine direct-connected to a 270-k.v.a. generator furnishes the power. The crew consists of 11 men per shift. Operating in the Ohio River near Pittsburgh this dredge averaged about 7,000 tons of gravel per day, operating practically continuously.¹

On canal work near New Orleans, a small ladder dredge was used. The width of cut was 35 ft., and it was handled by a dredge mounted on a 22- by 60-ft. hull, having a ladder equipped with 32 buckets of 6-cu. ft. capacity. The material excavated

¹ *Excavating Eng.*, May 1924.

was swampy muck. The average monthly output was 24,000 cu. yd.¹

Excavation in the Fox River, in Wisconsin, was accomplished by a ladder dredge discharging onto belt conveyors which delivered the material into a hopper on a scow; from there the material was transported by conveyors mounted on several scows until it was finally deposited on shore. The dredge was equipped with 39 buckets of 5-cu. ft. capacity. The hull swung on a stern spud, and the width of cut was about 145 ft. The hull was also equipped with a walking spud to move the dredge forward. A crew of nine men operated the dredge on this work.

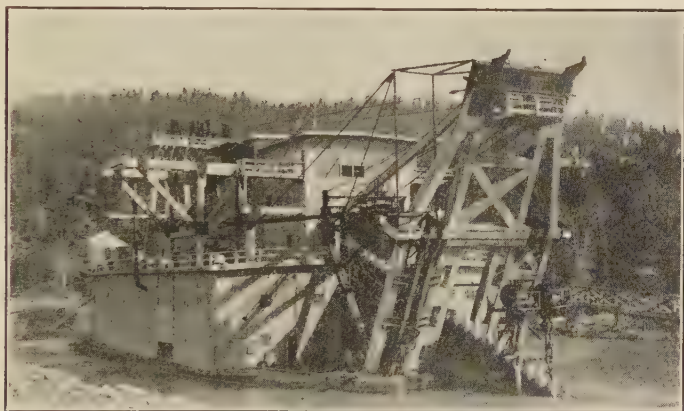


FIG. 74.—An 18-ft. gasoline-driven placer ladder dredge.

An output of 400 cu. yd. per hour was made by this outfit on a test run.²

A ladder dredge was used on the Yakima reclamation project in Washington for enlarging a canal. The hull, which was 80 by 30 by 6 ft., with a draft of 5 ft., was too narrow for stability, but had to be built this way in order to pass through locks in the canal. The buckets were of 3½-cu. ft. capacity. A hydraulic monitor supplied by a 6-in. centrifugal pump was used to wash down the banks ahead of the dredge. This plant was largely experimental and for this reason a considerable amount of time and money was spent in trying to adapt the machinery to existing conditions, so that very little work was done for several

¹ *Eng. News*, Aug. 14, 1913.

² *Eng. News*, Oct. 25, 1906.

months. A total of 921,000 cu. yd. were moved between December 1909 and October 1911; the material was mostly gravel, some of it cemented. The spoil was deposited on the canal banks by 70-ft. belt conveyors mounted on the dredge. A great deal of trouble was experienced in keeping the spoil banks in place and the semi-liquid material flowed out over valuable orchard lands. The ladder broke down twice on the job, probably on account of a torsional strain caused by digging mostly on one side. Fuel was hauled 3 miles over rough country roads.

The following cost data are given, the depreciation including the entire cost of the plant.

TOTAL EXCAVATION, 930,723 Cu. Yd.

	Cost	Unit Cost
Labor, dredge.....	\$ 26,960.63	0.029
Labor, spoil banks.....	31,159.06	0.034
Fuel.....	33,043.07	0.036
Plant maintenance.....	52,327.40	0.057
Plant depreciation.....	41,432.53	0.045
Total.....	\$184,922.69	0.201

The operating force consisted of nine men and four horses, and wages were: operator, \$5 per day; spudman, \$3.83 per day; fireman, \$3.33 per day; oiler, \$3 per day; deckman, \$2.50 per day; team and driver, \$4.50 per day.

The maximum excavation per 8-hr. shift was 1,429 cu. yd., and the average per shift was 557.9 cu. yd. Average excavation per actual working hour was 128.7 cu. yd. The per cent of time lost totalled 49 per cent, as follows: moving, 10 per cent, repairs and miscellaneous, 39 per cent.¹

GRAPPLE OR GRAB BUCKET DREDGES

The grapple dredge differs from the dipper dredge only in the digging mechanism. The dipper dredge is a power shovel mounted on a hull, while the grapple dredge is a derrick and grab bucket mounted on a hull. Two types of buckets are used on grapple dredges—the clam-shell and the orange-peel buckets (see Fig. 75). Buckets are designed and proportioned differently according to the kind of materials they are to work in. For soft digging a light bucket can be used, but where the material is

¹ *Eng. Contr.*, Sept. 11, 1912.

hard the bucket must have enough weight to enable it to dig into the material as the jaws are closed. Buckets of from 6- to 12-cu. yd. capacity are common for these machines.

The machinery for operating a grapple dredge is very simple. All that is needed is an engine connected to the drums which operate the lines for raising and lowering the bucket and opening and closing the bucket, and also the swinging lines.

The boom on this type of dredge may be quite long, much longer than on dipper dredges. Booms as long as 240 ft. have been used on grapple dredges, which enable these machines to deposit excavated material at considerable distances from the digging point.



FIG. 75.—Typical orange-peel grapple dredge.

The grapple dredge is moved ahead by "pull-ahead" lines. On one type there are three auxiliary drums, two of which operate the two spuds and the other draws a line attached to the bucket. To move ahead, the bucket is dropped ahead of the machine, the hoist line is slackened, and then the "pull-ahead" line is wound in, thus pulling the dredge ahead. On other dredges movement is secured by shore lines attached to deadmen, or anchor lines.

GRAPPLE-DREDGE OPERATION

The grapple dredge is easily constructed and particularly well fitted for certain jobs of excavating. Since there is practically no limit to its digging depth, it can be used where dredges of

other types cannot reach. When equipped with a heavy bucket armed with special digging teeth, the grapple dredge can handle hard material, even large rocks, stumps, and debris. This dredge is also useful on levee construction under favorable conditions, as it has a long reach and can deposit material well back on the shore. It is not very extensively used for the excavation of drainage channels, as work of this nature usually is carried on under conditions better suited to dipper dredge operation.

The crew of a grapple dredge ordinarily is small, consisting of an operator, a fireman, and a deck hand or two.

Clam-shell buckets are best suited to digging in hard, packed sand or layers of homogeneous material, as they load by scraping up the material. When the material to be excavated contains stumps, rocks, etc., and is rough in contour, the orange-peel bucket will work to best advantage.

A channel, known as the Knights' Landing cut, in California was dug by grapple dredges equipped with clam-shell buckets. This channel has a bottom width of about 400 ft. for part of its length, and at the upper end is 600 ft. wide for some distance. Except on the 600-ft. section, all material was handled directly from cut to spoil bank by the dredges, equipped with 4- and 5-cu. yd. buckets and booms from 170 to 240 ft. long. All kinds of material were handled, except solid rock; the depths of cuts did not exceed about 14 ft. Material could be placed in the spoil banks without rehandling at distances of from 300 to 350 ft. from the point of excavation by the machines with 240-ft. booms. The average output per 22-hr. day on this job was from 2,500 to 3,000 cu. yd. per dredge.¹

¹ *Eng. Record*, Vol. 74, No. 12, Sept. 16, 1916.

CHAPTER IX

TRANSPORTATION OF EXCAVATED MATERIALS

On any excavation job where the material is dug by power shovel or dragline machine and the dump, embankment, or spoil bank is at such a distance from the digging operations that the material cannot be disposed of directly, means must be provided for mechanical transportation of the material. Too much attention cannot be given to the planning and handling of this transportation feature, for the economical handling of a shovel or dragline job depends as much on proper transportation facilities as on any other one item. The output of the digging machine is nearly always limited by the ability of the transporting equipment to dispose of the material.

The usual means of transporting excavated materials are by wagons, motor trucks, or trains of dump cars hauled by small locomotives. On some railroad operations, such as excavation for additional width along existing lines, standard size gondola or flat cars hauled by regular locomotives are used. Other transportation methods include scows and tug boat, belt conveyors, and cableways.

WAGONS

Dump wagons hauled by teams or power tractors are used extensively for transporting excavated materials on road-grading jobs, levee construction, and from gravel pits or other pit excavations. Team-hauled wagons can be used economically where the haul is not very long, and the installation of excavating plant is not large. The ordinary team-hauled dump wagons have capacities of from 1 to $2\frac{1}{2}$ cu. yd. Larger sizes, up to 5-cu. yd. capacity, can be had for tractor hauling.

In general, it may be said that the use of dump wagons for transporting excavated materials should be limited to jobs where (1) the size of the job does not warrant the installation of track and car equipment; (2) the work is so situated that railroad equipment cannot be used, such as building foundation excavations or other operations in cities; (3) road-grading jobs where

the total quantity excavated may be large, but is distributed in alternate cuts and fills over a considerable distance.

The number of wagons to be used on a given job will be determined by the size and capacity of the excavator, the length of haul, and the kind and condition of roads over which the hauling is to be done.

According to Gillette ("Earthwork and Its Cost"): "The average speed of a team walking steadily over hard roads with a large load, and returning at a walk empty, is about $2\frac{1}{2}$ miles per hour or 220 ft. per minute."

Recently gasoline tractors with caterpillar tread have been used to some extent to haul trains of dump wagons or trailers. Where teams are scarce and expensive the use of the tractor will probably be economical.

MOTOR TRUCKS

Under favorable conditions the motor truck can be used in place of team-drawn dump wagons for transporting excavated materials. The motor truck has greater capacity and power and can make much greater speed than team-drawn outfits. The truck, however, cannot always go where a team can. Another feature to be considered when comparing wagons and motor trucks is that waits for loading and unloading are more expensive in the case of trucks. The trucks can be used most economically where the hauling time is great as compared to the idle time. Due to its capacity and greater speed, the truck is better suited to long-haul work than the wagon.

DUMP CAR TRAINS

On large-scale excavating jobs, such as channel improvements, canals, excavations for dams and levees, etc., the usual means of transportation is by dump-car trains hauled by small steam, electric, or gasoline locomotives. The steam locomotive, or dinkey is most commonly used. The cars may be single- or double-truck mounted; single-truck cars are usually of 3- to 4-cu. yd. capacity, while the two-truck cars, used on standard gage track, are of 12- to 20-cu. yd. capacity. All cars dump from either side; the larger ones are equipped to dump by air pressure. The smaller cars are built for use on narrow gage track, usually 36-in. gage.

For narrow gage outfits the 18-ton locomotive is commonly used, trains of from six to twelve 4-cu. yd. cars being hauled. On



FIG. 76.—A 40-ton standard-gage steam dinkey locomotive.



FIG. 77.—A 50-ton locomotive and 12-cu. yd. side-dump cars.

standard-gage installations where 12-cu. yd. cars or larger are used, 40- to 50-ton locomotives are employed for hauling.

Trains are made up of from 5 to 15 cars, depending on conditions of track, grades, haul, etc. (see Figs. 76 and 77).

Careful attention should be given to track layouts, location of crossovers and switches, and the condition of the track. It is well to use heavy rail where a considerable amount of hauling is to be done; 60- to 70-lb. rail is recommended. Sharp curves should be avoided if possible and grades should be kept as flat as conditions will permit. A 2 per cent grade is about as steep as can be used with trains of economical size.

The following descriptions of transportation layouts and methods as used on the work of the Miami Conservancy District are typical of the usual practice on similar work.

Borrow-pit Material at Dams.—The transportation of material from borrow pits to dredge pumps was an important feature of the work at Englewood, Germantown, and Huffman dams, where a total of more than 5,000,000 cu. yd. of material was hauled. The general system was about the same at all three places, with only such modifications as the topography or the nature of the work demanded. All the material was loaded into 12-cu. yd., standard-gage, air-dump cars, which were hauled in 5-car trains by 40-ton, 4-wheel saddle tank locomotives. Track grades were limited to about 2 per cent against the load, and curves were not sharper than about 300 ft. in radius. Tracks were laid to line and grade, and were carefully kept up, and 60- to 70-lb. rail was used, with a tendency to favor the heavier rail because of the fact that it held its line better, and was in better shape for moving. Because of the use of dragline machines in the borrow pits, the spacing of the successive loading tracks was from 125 to 150 ft. apart, and one track location served a large quantity of material (approximately 10,000 cu. yd. per 100 ft. in most cases). Therefore more careful laying and maintenance of tracks was justified than might be the case in a steam-shovel cut, or on a spoil bank where frequent moving of the track is a part of the regular routine. The tracks were laid out with a loop at the unloading end, except at Germantown where the topography would not permit. At the pit, a cross-over completed the circuit. That system, with a loop at one end and cross-over at the other, turned each train end for end each trip. This was an advantage, in that it resulted in dumping the cars on alternate sides each trip, whereby they were more easily kept clean than when dumped from one side all the time.

Track grades were important, and were laid out carefully. On a 2 per cent grade a 40-ton locomotive could handle effectively a train of five loaded cars. The continuous service of a track maintenance gang was required to keep the tracks in good shape. At Huffman and Germantown this track gang consisted of a foreman and from five to ten laborers. At Englewood, where duplicate equipment was used, the track-maintenance gangs were increased correspondingly. These track gangs also attended to the moving and re-laying of the loading tracks.

Continuous repair work on cars was necessary. It was the practice to have a number of extra cars on hand, as there were always a number of cars out of service on the repair track. At Englewood where six 5-car trains were in service, the car repair gang consisted of two or three men, and at least eight or ten extra cars were kept on the job to permit the circulation over the repair track. At Germantown and Huffman where ten cars were in continuous service, about four or five extras were required, and one man at each place was able to look after the repair work. It became standard practice to line the car bottoms with sheet metal as a matter of economy, and to facilitate clean dumping.

The difficulty of keeping the locomotives in continuous service has already been mentioned. At all of the jobs the water available was very hard, and in spite of the use of various boiler compounds frequent rolling and replacement of flues was unavoidable. Wherever it was economically feasible, an extra locomotive was held on the job to be put into service as needed while one of the others was being overhauled. Where this was not feasible most careful attention was necessary in order to maintain continuous service, and much and expensive emergency repair work was the result.

On all of the jobs the quantity of material put into the dam was limited by the capacity of the dragline excavators in the borrow pits. The transportation problem, then, was so to organize that the draglines would be kept supplied with cars and maintain a continuous feed to the dredge pumps. Two 5-car trains at Huffman and at Germantown served the one dragline at each place most economically. Train lengths were increased by one or two cars occasionally, but normally the extra cars were not needed. A third train might have saved some little delay at the dragline at times, but the extra cost was not warranted in

the long run. At Englewood, where there were two draglines in the borrow pit with a third to be called upon if needed, six 5-car trains were kept in service most of the time. (The average length of haul was longer than at Huffman or Germantown.) Either train could serve either machine, and as a result of a carefully worked out system there was practically no waiting for cars at the draglines, and very little idle time for the trains.

Below are given detailed cost figures of the hauling and dumping of more than 700,000 cu. yd. of borrow-pit material at the Huffman dam, where the average length of haul was 2,000 ft.

	Unit Cost per Cubic Yard	Per Cent of Total
Superintendence and overhead.....	\$0.010	4.1
Labor.....	0.107	44.2
Coal.....	0.034	14.1
Other supplies.....	0.025	10.3
Plant depreciation.....	0.066	27.3
	\$0.242	

These figures cover the whole period of work and include adjustments for winter work and miscellaneous expense. Labor was being paid from 40 to 46 cts. per hour, locomotive runners 50 to 60 cts. per hour, firemen 45 to 50 cts. per hour and brakemen 45 to 50 cts. per hour. Coal was charged out to the job at an average price of from \$5 to \$5.50 per ton. Representative costs for similar hauling at Englewood were about as follows:

	Unit Cost per Cubic Yard	Per Cent of Total
Superintendence and overhead.....	\$0.015	6.2
Labor.....	0.105	43.8
Coal.....	0.026	10.8
Other supplies.....	0.034	14.2
Plant depreciation.....	0.06	25.0
	\$0.240	

Average length of haul about 3,000 ft.

Wages and coal costs were practically the same as at Huffman.

Coal consumption per locomotive was about two tons per 10-hr. shift, under fairly favorable conditions. The cost of oil and waste averaged about \$2 per train per shift.

Waste Material from Channel Excavation.—The transportation of material from the river-channel excavations to waste banks at Hamilton was similar in general to the work just described. The same type of equipment was used. The cars were loaded by dragline machines, as at the dams. Dumping the material into a spoil bank instead of into the hog boxes, was the chief difference between this work and that just described.

At Hamilton the locomotives were heavier than those used at the dams, being 50-ton locomotives of the same general type as



FIG. 78.—Hauling from channel excavation at Hamilton, Ohio.

The dragline loaded 12-cu. yd. dump cars, which were hauled by 50-ton locomotives in trains of 10 to 12 cars.

the 40-ton engines used at the other places. The average length of haul was about 5,000 ft. The limiting grades in the track layout were $1\frac{1}{2}$ per cent, and the sharpest curves were 300-ft. radius. At one place where a 1 per cent grade was followed by a 350-ft. radius curve, and then a $1\frac{1}{2}$ per cent grade, a 50-ton locomotive was able to handle a train of 10 loaded cars. Part of the time on this work, trains of 12 or 13 cars were used, but in such cases it was necessary to use a pusher on the $1\frac{1}{2}$ per cent grades; 60- to 70-lb. rail was used in the track, and the track was kept in first-class condition, especially those sections of it which seldom required moving.

On the spoil banks a spreader car was used in order to avoid continual throwing of the track. This permitted moving the track over about 12 ft. at a time, and justified more careful maintenance of the track on the dump than otherwise would have been the case. A small dragline machine was used successfully for moving track on one of the spoil banks. This has been described more fully in Chap. V.

There was the same difficulty here in keeping locomotives in continuous service, as has been mentioned before, but an extra locomotive was available at Hamilton which could be used while another was being overhauled. One or two men were kept at work continuously making car repairs. Table XVI shows the cost of repair parts used on three 50-ton locomotives at Hamilton for a period of 1 yr., during which time a total of 500,000 cu. yd. of material were hauled an average distance of about 5,000 ft. (see Fig. 78).

Cost records are available on the hauling and spreading of 400,000 cu. yd. of material at Hamilton. This was for one season's work, but does not include the extra cost due to winter expenses, etc. On the other hand, it does include the cost of dumping and spreading on the spoil bank while the costs given for similar work at the dams have in them no charge for spreading.

UNIT COSTS OF HAULING, DUMPING, AND SPREADING WASTE MATERIAL
FROM CHANNEL EXCAVATION AT HAMILTON

	Unit Cost per Cubic Yard	Per Cent of Total
Superintendence and overhead.....	\$0.010	4.4
Labor.....	0.151	66.2
Coal.....	0.017	7.4
Other supplies.....	0.005	2.2
Plant depreciation.....	0.045	19.8
	\$0.228	

Average length of haul 5,000 ft.

Total quantity handled 405,000 cu. yd.

Labor at Hamilton during this period was being paid 35 to 40 cts. per hour. The coal used during this season cost only about \$3.50 per ton on the job, while the average cost of coal used on the Hamilton job was approximately \$5.50 per ton. In other words, the low price of coal used during this particular

period cuts about 1 ct. per cubic yard off the cost of hauling. To bring this up to an average for the whole job another 3 to 4 cts. should be added to cover winter costs, unproductive work, idle time, etc.

TABLE XVI.—SUPPLIES AND REPAIR PARTS FOR THREE 50-TON LOCOMOTIVES FOR ONE CALENDAR YEAR

Oil and greases.....	\$ 322.53
Lanterns, wicks, etc.....	31.40
Valves, cocks, etc.....	160.88
Gaskets, packing, etc.....	55.42
Injectors and parts.....	78.48
Brake heads.....	42.08
Brake shoes.....	114.80
Brake rod.....	10.00
Soft plugs.....	8.67
Driving-box brasses.....	75.00
Brass bushings.....	9.20
Dick belt.....	60.06
Babbitt.....	3.84
Dump air hose.....	9.17
Fire hose.....	62.50
Steam hose.....	29.00
Boiler compound.....	86.63
Muriatic acid.....	15.00
Lumber.....	23.68
Paint.....	3.65
Steel, 53-lb. 2-in.....	13.25
Flues and ferrules.....	344.98
Prest-o-Lite and oxygen.....	54.77
Sand dryer.....	65.25
Window glass.....	8.91
Waste.....	23.00
Tools (small).....	63.89
Retreading six pair wheels.....	120.00
Miscellaneous, iron, bolts, etc.....	133.96
Total for three locomotives.....	\$2,030.00

This gives an average cost of hauling, dumping, and spreading at Hamilton of about 28 cts., for a haul of 5,000 ft., with $1\frac{1}{2}$ per cent maximum grades, 50-ton locomotives and 10-car trains, as compared with 24 cts. at the dams, where the hauls were 2,000 to 3,000 ft., the maximum grades 2 per cent, and where 40-ton locomotives were used with 5-car trains.

At Dayton, about 500,000 cu. yd. of waste material from channel excavation was moved to spoil banks by means of scows and

tug boat. This has been referred to in Chap. V, in the discussion of the dragline dredge. The average length of haul was about 3,000 ft. An ordinary load for a scow was from 200 to 250 cu. yd. The unit cost of hauling by this method during a favorable period, not counting extra expense for winter work, delays, etc., was about 26 cts. per cubic yard.

BELT CONVEYORS

Belt conveyors have been used to advantage on certain jobs for transporting excavated materials. One of the most notable recent uses of this system was in connection with the construction of the Wanaque Reservoir dams in New Jersey. This project included the construction of several earth dams and dikes with a concrete core wall in the principal dam; and two concrete dams. All of the fill for the dams and materials for the concreting operations were handled by a system of belt conveyors which totalled $2\frac{1}{2}$ miles in length (see Fig. 79). A top-soil conveyor 3,000 ft. long having a 30-in. belt handled top soil at a rate of 175 cu. yd. per hour when running filled. Ordinarily it handled about 800 cu. yd., loose measure, per day. The top soil was dumped into a hopper over a short belt which carried the material to the main belt. The main conveyor was supported on trestle construction of light poles. At the dam end, the main line discharged into a steel chute which emptied into an elevated hopper.

Serving steam shovels in the borrow pit were two conveyors—one 28-in. belt 1,000 ft. long and the other a 32-in. belt 900 ft. long. These were mounted on wooden frames on wheels and could be shifted as the shovels entered new cuts. The speed of operation of the main conveyors was about 400 ft. per minute. All of the belts were motor operated, the motors ranging from 3 to 100 hp.

It was found that the conveyor system as developed on this job was very satisfactory. Grades as high as 25 per cent were negotiated in handling sand and gravel for concrete, and a portion of the top-soil conveyor had a rise of 20 deg. Of course, all lines must be straight; changes of direction require additional separate conveyors, angling as desired. The conveyors, however, are easy to install and no great mechanical difficulties are involved.¹

On a large stripping operation in Australia, belt conveyors were used to transport the overburden excavation from the

¹ *Eng. News-Record*, Vol. 95, No. 7.

shovels. Main conveyors were built on the original ground level, running parallel to the face of the cut. The shovels deposited into feeders from which the material was carried at right angles to the face of the cut and deposited on the main conveyor.

The feeder conveyors were short 38-in., eight-ply rubber-covered belt running at 350 ft. per minute, and were mounted on rails paralleling the movement of the shovel along the cut. The

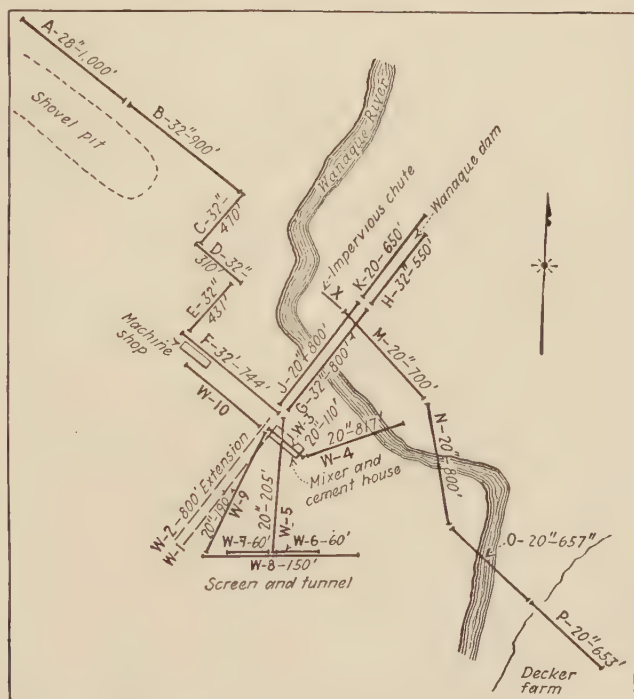


FIG. 79.—Diagram of belt-conveyor layout at Wanaque dam.

On this job all materials, including earth for the dam, gravel, and concrete, were handled by belt conveyors. (From *Eng. News-record*, Vol. 95, No. 7.)

main conveyor was composed of four sections, each separate within itself. All belts were electrically driven. The conveyors were built on steel trusses supported on four-wheel trucks.

A boom stacker received the material at the side of the main cut and distributed it evenly over the dump. This installation handled an average of 40,000 cu. yd. of material per month, working 24 hr. per day for 6 days a week.¹

¹ *Excavating Eng.*, November 1926.

PART II

CHAPTER X

SIZING UP AN EMBANKMENT JOB

The selection of a method for handling the construction of an embankment should be made only after consideration of the various factors applying to the particular job, just as was recommended in the case of excavation. For every job of embankment construction, of course, an excavation must be made to furnish the material, so that the selection of methods for handling embankment work must be made with due consideration of the means of obtaining the material. Therefore, the principal factors which should influence the selection of method and plant for excavation work, as outlined in Chap. I, should be reviewed in connection with this discussion of embankment methods.

Embankment construction may be divided into two broad classifications: (1) tight fills, such as dams, reservoirs and levees; and (2) fills which ordinarily need not be watertight, such as highways fills and railroad embankments. Settlement often is an important factor, however, in the consideration of types of embankments. Naturally, earth dams, in addition to being watertight, must be designed and constructed in such a manner that there will be a minimum of settlement of the fill. In the case of levees, while watertightness is essential, a greater percentage of settlement may be allowed than for dams, which are higher structures and usually impound water for considerable lengths of time. Settlement may be an important factor in connection with the construction of certain highway fills, especially if paving or permanent surfacing is to be applied soon after the construction of the embankments. It may be stated, then, that for either of the broad classifications of embankment construction, the matter of settlement should be considered by the designer and constructor, as the relative importance of this factor will have considerable bearing on the method to be adopted for handling the work.

The usual types of earth dams, designed to impound water continuously or intermittently, may be classified as rolled fill,

hydraulic fill and semi-hydraulic fill. The designer of structures of these types should have both a thorough knowledge of the kinds of materials suitable for such works and of the approved methods for handling their construction. The constructor, likewise, should be familiar with the principles involved in the design of the structures and the kinds of material best suited to the various types.

The following considerations are of importance in connection with the design and selection of plant and method for the construction of earth dams:

1. Nature of material, clay, sand, gravel, etc.
2. Distance of borrow pit from dam site.
3. Elevation of borrow pit with respect to dam.
4. Quantity of material needed.
5. Water supply available (very important for hydraulic and semi-hydraulic fills).
6. Disposition of stream flow during construction period.
7. Provision for handling floods during construction period.
8. Relation of embankment construction to concrete or other work connected with the structure.
9. Items considered in connection with excavation jobs, such as availability of labor, transportation facilities, time allowed for completion, power or fuel available, etc.

It should be remembered that the specifications for placing various types of dam embankments often are very explicit with regard to the actual deposition of materials. The foregoing applies particularly to hydraulic and semi-hydraulic embankment construction, although rolled-fill specifications are well standardized also.

In the case of all but hydraulic fills, the materials must be brought to the dam site in a dry or nearly dry condition. Therefore, consideration may be given to the various methods and plant for dry borrow pit excavation and the transportation of the dry material to the structure. Most earth dams are so large that mechanical means of excavating and transporting the material will be most economical. On small jobs, teams and scrapers may be employed to advantage, provided the haul is not too long.

Hydraulic-fill construction requires the placing of the embankment by hydraulic methods, so sluicing often may be employed to handle the excavation where conditions are favorable.

Aside from the plant necessary for the excavation and transportation of the material to the dam, the following will be needed to handle the various types of dam construction:

1. *For Hydraulic Fills*.—Dredge pumps to boost the material to the fill (unless gravity sluicing is possible); pipe lines or flumes to convey the material where needed; small draglines, shovels, graders, or other machines to build up and maintain the shoulders which confine the sluiced material and the core pool; additional pumps for water supply, boosters, etc.; power units for the pumps; derricks to handle heavy equipment; hydraulic giants (where "hog-boxes" are used, see Chap. XIII); equipment for preparation of foundation of dam.

2. *For Semi-hydraulic Fills*.—Hydraulic giants to sluice the fine material to the center; pipe lines to supply the giants with water; pumps; power units; derricks; trestles or floats to support the giants and pipe lines, equipment for preparation of foundation.

3. *For Rolled Fills*.—Spreaders, such as road graders; sprinkler wagons or hose and pipe lines; harrows; rollers; pumps to supply water needed; equipment for preparation of foundation.

While there are limitations to the choice of methods for handling fills of the types mentioned, it is often possible to work out refinements and improvements in the application of the methods and in the equipment, that will save time and money. For example, dredge pumps and pipe lines were among the equipment used extensively to excavate and transport materials for the hydraulic fill dams of the Miami Conservancy District. By experimentation, in cooperation with manufacturers, improved pump shells were made which greatly increased the life of the pumps, and a dredge-pipe material was found which was far more durable than that commonly used up to that time. Also, an improved type of revolving grizzly was evolved to facilitate the removal of oversize material, and many refinements of methods were worked out.

Levee construction may be handled by many types of plant; the choice depends much on the locality, the nature of the material, the proximity of the stream to the levee, the position of the material, *i.e.*, above or below the water level, and the relation of the levee construction to excavation work at hand, such as channel improvement, ditching, etc. Levees may be built by dragline excavators, power shovels, dredges, cableway

excavators, power drag scrapers, and ordinary wheel or drag scrapers.

Roadbed embankment construction, either for highway or railroad improvements, is nearly always tied up with excavation work on the same project, and therefore methods of handling such embankments must be considered in connection with the excavation. Long, high fills require special handling; special borrow pits often must be provided and attention must be given to haul distances on work of this nature. Ordinarily the placing of roadbed embankment material is simply a matter of dumping the material where needed and raising the dump to the required height, allowing the material to take its natural slope. Sometimes, however, it is important to minimize settlement of the fill, and in such cases special methods must be employed to secure the desired results.

In conclusion, it may be said that a proposed job of embankment construction should be viewed from the standpoint of the various elements involved, including the means of securing the material. Therefore, the constructor should be familiar with excavation methods and equipment and means of transporting materials, as well as the various methods for actually handling the embankment.

CHAPTER XI

LEVEE AND ROADBED EMBANKMENT

While there are certain similarities in the physical aspects of levee and roadbed embankments quite dissimilar methods may be used in their construction, and therefore each type of embankment will be discussed separately.

LEVEE EMBANKMENTS

Levees are long and relatively narrow fills thrown up along the banks of streams, or, rarely, lakes, the purpose of which is to prevent the overflow of land adjacent to the streams or lakes at times of high stages. A levee must be fairly impermeable, it must be of large enough cross-section to be stable and to withstand water pressure on one side for varying lengths of time and it must be resistant to erosion.

A standard specification for levee construction (used on the Miami Conservancy District work) provides that:

The embankment shall be carried up in approximately horizontal layers extending entirely through the fill. Where the material is deposited wet, that is, from under water excavation, the layers shall not exceed 3 ft. in thickness; where the material is deposited dry the layers shall not exceed 1 ft. in thickness and shall be compacted by rolling and sprinkling or by other satisfactory means. The foundation shall be cleared of all vegetable and perishable material and shall be roughened by plowing or harrowing. All large stones shall be removed from the fill.

Methods of handling the construction of levees will be dependent largely on the location and quality of the materials from which they are to be built. If the borrow pit is on the land side of the proposed structure and is dry, obviously it will be necessary, in order to secure impermeability, to handle the construction somewhat like a rolled-fill job. On the other hand, if the materials are obtained from the stream bed and are saturated, it is often possible to build a satisfactory and safe levee by simply depositing the material in the required location.

Another factor to be considered is that very often levee construction is tied up with a job of channel excavation, in which case the methods of handling the material and the plan to be used must be adapted to the excavation plans. Levees have been built successfully by practically all of the types of plant described in Part I, except dredges of the ladder type; and reference should be made to that part of the book for detailed descriptions and data regarding the operation of the various excavating machines.

Where the levee work is all in the dry, that is, where the borrow pit and the levee foundation are both in fairly stable material, and where side borrow is available, the work may be handled by teams and scrapers, elevating graders and wagons, steam shovels and wagons or cars, dragline excavators or cableway excavators.

On small jobs, where the haul is not too long and the volume per lineal foot of levee is not large, scrapers may be used to advantage, unless other equipment is at hand and might handle the levee fill as part of other work. On larger jobs, and under similar conditions, where the borrow pits are close enough that the material may be handled by one throw from cut to fill, dragline excavators are perhaps the machines best adapted to handle the work economically. When the borrow pits are not adjacent to the proposed levees and material must be hauled in, the choice of equipment will usually be between shovels, draglines, elevating graders, or cableways. The cableways present the advantage that no hauling equipment will be needed; however, there are limitations to the economical span of cableways, and consideration must be given to cost of installation and moving of the plant. Elevating graders may be used where the topography and character of material are suitable for their operations. Shovels can be used almost any place, providing the excavation is in the dry.

Levee construction in wet or marshy lands, such as are found in Mississippi and Louisiana, may be handled to advantage by floating dredges. Charles W. Okey, in a bulletin of the U. S. Bureau of Public Roads entitled "The Wet Lands of Louisiana and their Drainage," recommends grapple dredges equipped with orange-peel buckets for work of this kind. This type of dredge, because of its long boom, can deposit the material at some distance from the ditch or stream, thus providing an ample berm between the levee toe and the stream bank; it also can select the material to better advantage than can the dipper dredge.

When levees are built in these wet areas, care must be taken to prevent slipping out of the embankment. Usually a shallow ditch should be cut along the center line of the proposed levee before any material has been deposited, so as to provide a keyway for bonding of the embankment to the original surface. When the material is a thick muck, it will be best to omit the keyway ditch until after the first layer of embankment has been placed and has dried out somewhat. Then a ditch may be cut along the toe of the levee slope opposite the dredge and this ditch may be filled with impervious silt dredged from the bottom of the canal.¹

According to *Engineering News*, Vol. 75, No. 16, dipper dredges were used somewhat extensively for the construction of levees along the Illinois River. The dredges floated in borrow pits located about 200 ft. from the low-water section of the river. This method of construction produced levees that are quite rough and irregular in section.

In California, grapple dredges with clam-shell buckets of 5- or 6-cu. yd. capacity have been used extensively to construct levees from a sandy material.

Where conditions are favorable, hydraulic dredges may be used to advantage to build levees. Among the favorable conditions are (1) an ample supply of material suitable for hydraulic dredging, (2) facilities for disposition of the excess water from the dredging operations, (3) ample waterway for the dredge within reasonable distance of the levee, (4) an unobstructed beach between the dredge and the levee, (5) sufficient quantity of work to warrant the installation of a dredge plant.

Levees can be built up by the hydraulic method on slopes as steep as 1 to 1 directly from the discharge pipe by the use of so-called "window" or "shutter" pipe and slope boards. The "window" pipes are lengths of standard dredge pipe with openings in the bottom of the pipe at intervals. The openings are fitted with steel-plate shutters which may be opened as desired, or sometimes no shutters are used at all. The usual method of using these window pipes is to connect several lengths together in the discharge line where the fill is to be made, the whole line being supported on a trestle, and to allow portions of the discharge to pass through the various openings. A length or two of solid pipe is carried beyond the window pipe so that the surplus

¹ GILLETTE, H. P. in "Earthwork and its Cost."

water will not wash out the embankment as it flows away. The material is pumped at such a velocity that practically all of the solids will drop out through the window openings. These openings, in a 15-in. pipe, are usually about 4- by 6-in., with the 6-in. dimension lengthwise of the pipe, and they are spaced about 3 to 4 ft. apart. Often slope boards are set along the slopes to control the width of the fill. These boards are simply long pieces of timber, about 1 by 12 in., or steel plates, which are set up on edge and fastened to stakes at the desired places. After the fill has extended to the boards they are removed and set up again at the next lift.

Hydraulic-fill levees can be built, of course, without the use of the window pipe, in which case standard methods are followed.

The dredge cannot operate at maximum efficiency on levee work of the kind described above, principally because of the time consumed in shifting pipe lines, building trestles, etc. Where practicable the work can be speeded up by the installation of a Y-connection in the main discharge line from the dredge so that two lines may be used. While one line is being shifted filling may be carried on through the other.

To build levees successfully and economically by the hydraulic-dredge method skilled operators should be employed on the dredge and an experienced crew should handle the deposition of materials. It is essential that the flow of material be steady and uniform, and the control of the quantity of solids pumped depends on the operator in the pumproom. Manipulation of the window pipe, such as adjustment of the window openings and changes of pipe sections, requires a crew accustomed to work of this sort.

No matter what method is used to construct levees, due consideration should be given to the matter of settlement or shrinkage, and the embankment should be built to sufficient height and section to provide for the estimated settlement. The amount of settlement will vary considerably under different conditions. The elements that will determine the settlement are (1) the nature of the material, (2) the degree of wetness of the material when placed, (3) the method of placing it, and (4) the amount of settlement of the original ground due to the additional weight of the embankment. Light materials, such as dry loam and earth, will compact and settle much more than sand or gravel; thoroughly saturated gravel or clay will settle very little, especially if they are excavated from below water and are dropped

into place from a considerable height. The latter condition occurs when a levee is built by draglines or grapple dredges which excavate from ditches or rivers and unload their buckets by dropping the material into the fill. On the Miami Conservancy District work a levee about 12 ft. high built by dragline of dry loam and gravel showed an average settlement of 4.3 per cent after 2 yr. In another place where the levee, 20 to 25 ft. high, was built by dragline machines from wet river gravel dumped directly into place, the average settlement after 6 yr. was only one-fourth of 1 per cent. Another levee built of wet gravel but containing large lumps of clay, showed a settlement of 1.5 per cent after 6 yr.

It is difficult to estimate the amount of settlement accurately, and usually an amount of overfill is made which in the judgment of the builder will be ample to take care of the maximum shrinkage.

Where levees are built close to the banks of a river consideration should be given to erosion in times of high water, due to wave action and to the velocity of the flowing water. Slope protection will be necessary in some instances, especially on the outside of curves. Concrete slope paving or revetment is most frequently used at such places. When the levee slopes are not protected by paving or other applied coverings, a good sod is essential. To obtain a satisfactory growth of grasses, the levee slopes should be covered with a layer of good top soil after the embankment has been placed, unless, of course, the embankment material itself is of such material that a quick growth may be obtained. Sometimes sod is placed on the levee slopes and tamped or rolled down, but this is usually an expensive process, and is not justified unless immediate protection is necessary.

EXAMPLES OF LEVEE CONSTRUCTION

Levees on the Miami Conservancy District Project.—As part of the flood control works in the Miami River valley in southwestern Ohio, levees were built along the river channel through a number of towns.

The construction of levees was very often tied in with channel excavation, and construction methods and progress were so interdependent that only a limited amount of cost data could be recorded on levee construction itself. In many of these cases also, costs of levee embankment were not determinable, as the

levee work and the channel excavation were really one job and costs could not be separated.

Some of the levees were built from side borrow. Many of these were built by contract, as that seemed to be the most economical way to handle that particular class of work, and while the actual costs of work are not known in those cases, some of the contract jobs will be discussed and the contract prices will be given.

In some cases the levee work consisted in the construction of new levees, while in many other cases the work required was simply the raising of existing levees to an additional height. In the latter cases the work was very difficult and correspondingly expensive, as it was spread out over long distances with comparatively small yardage per lineal foot; the work involved long hauls; and the interference from trees, which usually line the banks of the old levees and must be preserved when possible, added to the difficulties of the job.

The most extensive work of this kind was at Dayton, where many miles of existing levees were raised to additional heights of 2 or 3 ft. Most of this work was done by a small caterpillar dragline machine with a 60-ft. boom and a $1\frac{1}{2}$ -yd. bucket, working along the foot of the slope, loading the material into 4-yd., 36-in. gage dump cars, which were run on a track on top of the levee, and hauled by 6-ton gasoline locomotives. In loading this material it was necessary to select open spaces between trees, or points where sufficient clearing could be done without injury to the large trees. Usually the cars could be loaded on top of the levees, but in some cases it was necessary to load in the river bed and haul out on a grade. Where the hauls were short, teams were used instead of cars. It is not possible to give any reliable costs of this kind of work as it was always a part of the channel excavation, and separate costs for the levee work alone were not obtained.

At Franklin Ohio, is a good example of levee construction by dragline, cars, and trestle. Here the excavation was from a projecting point in the river bank with deep cutting, trimming slopes, and interference from large stumps, which made the excavation costs considerably higher than they would have been from a favorable borrow pit. The levee was about 5,000 ft. long, had a maximum height of 13 ft. and was made 16 ft. wide on top so as to accommodate a double track, 36-in. gage.

The excavation was made by a steam dragline machine with 75-ft. boom and $1\frac{1}{2}$ -yd. bucket. The material was hauled in trains of eight or ten 4-yd. dump cars, over 36-in. gage track, by



FIG. 80.—Constructing levee at Franklin.

Material was hauled in trains of 4-cu. yd. dump cars by 18-ton dinkey locomotives. Track was built on trestles of two-post bents, 16 ft. apart.

18-ton dinkey locomotives. A trestle was necessary the whole length of the fill. This was built of two post bents, 16 ft. apart, with 6- by 8-in. caps and 12- by 12-in. stringers. Footing blocks were used in place of mud sills, in order to avoid the necessity of

leaving timbers lying crosswise in the levee. The caps and stringers and as much of the bracing as possible were removed before the completion of the fill. Figure 80 shows this levee under construction, with the trestle construction in the foreground, beyond which is the train dumping material into the fill.

There were 70,000 cu. yd. in this levee. It was built at a cost of 83.8 cts. per cubic yard, and the unit costs given below include the cost of excavation, transportation, trestle construction, plant depreciation, and all other expense properly chargeable to the work. The average haul was about 3,200 ft. Wages during the period of construction were about as follows: Labor 40 cts. per hour, dragline operators \$250 per month, locomotive runners 60 cts. per hour, firemen 56 cts. per hour, brakemen 46 cts. per hour.

UNIT COSTS OF LEVEE CONSTRUCTION AT FRANKLIN

	Unit cost per cubic yard	Per cent of total
Superintendence and overhead.....	\$0.07	8.4
Labor.....	0.393	46.9
Supplies.....	0.197	23.5
Plant depreciation.....	0.178	21.2
	\$0.838	

One of the levees at Troy, Ohio, which was built by contract, had a length of about 3,000 ft.; it followed an old ditch bank which was raised and widened to a top width of 8 ft., with side slopes of 2 to 1. The maximum fill was about 15 ft. The material required to complete the work amounted to 38,000 cu. yd., all of which was obtained from borrow pits, with an average haul of about 850 feet. This work was done with a $\frac{3}{4}$ -yd. revolving shovel and nine or ten teams. The contract price was 75 cts. per cubic yard.

Another levee at Troy, containing 6,400 cu. yd., was built with four slip-scraper teams, from side borrow. It was necessary, in this particular case, to use a wide, shallow borrow pit. The contract price was 50 cts. per cubic yard, including the surface dressing and seeding.

One of the channel excavation contracts at Troy contained an item of about 60,000 cu. yd. of levee embankment. This work was done with a dragline machine equipped with a 60-ft. boom and a 2-yd. bucket. The material was taken from borrow pits alongside, and practically all of it was put into place without rehandling. The trimming and sloping was done by hand. This was a variable fee contract, by the terms of which the contractor's fee depended on the actual cost of the work as compared to an agreed estimate, hence the actual cost of the work is available in this case, even though it was contract work. The estimated unit price, agreed to by the District and the contractor, was 38 cts. per cubic yard. The actual cost was 27 cts. per cubic yard, plus the contractor's fee and bonus, 8 cts. per cubic yard in this case, making the total cost to the District 35 cts. per cubic yard.

At Piqua, Ohio, the location of one of the levees was through a large pile of stone dust wasted from a marble quarry. It was decided to leave part of this dust pile as a core for the levee. The first plan was to cut the stone dust pile to the ground level on each side of the center line of levee, so as to leave the core undisturbed, with its slopes parallel with the slopes of the finished levee and its top 12 ft. wide and 5 ft. below the finished top grade. A steam shovel and wagon outfit was available for the job. The method outlined would require an extra amount of excavation in order that the shovel and wagons could work along the river side of the core. So it was decided to excavate with the shovel in the stone dust pile to a depth of about 3 ft. above the level of the adjacent street and to the width of the finished levee, allowing the dust beyond the cut to stand as steep as it would—about $1\frac{1}{2}$ to 1. This cut was made from the street side so that wagons could be loaded conveniently. As the shovel moved along it threw back a pile of dust for the core of the height and width originally intended. The surplus material, amounting to 5,600 cu. yd., was hauled out and used to make a core for part of the levee beyond the dust pile. The shovel then obtained from a nearby borrow pit material to finish the levee to grade.

One of the levees at Hamilton, Ohio, containing 65,000 cu. yd., was built by a dragline machine, under favorable conditions, from side borrow. The levee was about 4,500 ft. long, from 8 to 13 ft. high, with a top width of 8 ft. and 2 to 1 side slopes. A berm 15 ft. wide was left between toe of levee and edge of borrow

pit. The material was top soil and gravel and all of it was placed with one throw. The dragline machine was equipped with a 60-ft. boom and 2-yd. bucket. Following are the cost figures on this work. These figures include the cost of moving the dragline machine on to the work, a distance of nearly two miles, and crossing a canal, requiring about 10 days in all.

COST OF FORD LEVEE, HAMILTON
(Total quantity 65,200 cu. yd.)

		Unit cost per cubic yard	Per cent of total
Superintendence and overhead.....	\$ 800	\$0.012	6.5
Labor.....	8,014	0.123	66.8
Coal.....	1,050	0.016	8.7
Other supplies.....	825	0.013	7.1
Plant depreciation.....	1,323	0.020	10.9
	\$12,012	\$0.184	

Wages, at the time the work was done were for labor 38 cts. per hour, dragline runners \$50.50 per week, firemen 45 cts. per hour, team and driver 80 cts. per hour. Coal cost \$3.50 per ton on the railroad siding.

On the east side of the river at Hamilton, south of the Main Street bridge, was a piece of levee about 3,200 ft. long, and containing 112,000 cu. yd., built entirely from channel excavation. The greatest height of the levee was 28 ft. above the toe of the slope on the river side. It was built with a 100-ft. boom electric dragline machine carrying a 4½-yd. bucket. For nearly two-thirds of the distance the material could be placed with one throw, but for the remainder it was necessary to handle the material two or three times to get it from the excavation to its place in the levee. In some places it was necessary to excavate below grade to get enough material for the levee opposite. It happens that in this case the reverse condition, *i.e.*, having a surplus of excavation in places, did not occur. In such case the remedy would be to widen the levee in those places, or to pass the surplus material up or down stream a short distance to where there might be a deficiency.

Where the levee could be built with one throw the operation was simple. The material was river gravel, mostly wet, easy to handle, and easy to compact. The dry material was mixed with the wet, in the fill, in such manner that all of it was sufficiently wet to compact readily. The levee was completed to full height, as the machine moved forward, the section within reach of the machine, after each move, being brought up in layers. Figure 81 illustrates this work.



FIG. 81.—Dragline building levee from channel excavation.

Most of the material was placed with one throw, using an electric dragline with 100-ft. boom and $4\frac{1}{2}$ -cu. yd. bucket. The greatest height of the levee was 28 ft. above toe of slope on the river side. Material was river gravel.

Where the material had to be moved more than once, the excavation was thrown up in a windrow as far over as the boom would reach, and on the return trip the machine either put the material into place in the levee, or moved it over again that much nearer to its final position. It was estimated roughly that material could be moved three times by a dragline, in this way, more cheaply than by cars or wagons. Where more than three moves were necessary, it was worth while to figure on other methods of transportation. Figure 82 shows the machine just finishing a

second throw of material into place. The material in the foreground is to be moved again. That opposite the machine is in place in the levee but not shaped or trimmed. Beyond the machine, a piece of finished levee may be seen. An average day's work, on the one throw material with this machine, was 1,550 cu. yd. in two 10-hr. shifts. On the two-throw work, including what little there was that had to be moved three times, the machine averaged 1,200 cu. yd. per 20-hr. day, levee measurement. Separate costs are not available on this work.



FIG. 82.—Dragline making second throw of material into levee embankment. The material in the foreground is to be moved again. That opposite the machine is in place, but not shaped or trimmed.

On the west side of the river at Hamilton, above the Main Street bridge, is a levee about 2,000 ft. long, with a maximum height of 26 ft., which was built from channel excavation by a steam dragline machine with 60-ft. boom and 2-yd. bucket. The material in this levee was practically all gravel, part wet and part dry, and had to be handled from one to three times, some of it being taken from as far out as the middle of the river. This really was work for a larger machine, but none was available at the time. The total quantity, measured in the levee, was 46,000 cu. yd. It averaged at least two-throw work. An average day's work was 580 cu. yd. in place in the levee, for two shifts of 10 hr. each. Separate costs cannot be given, as this work also, was a part of the channel excavation.

At West Carrollton, Ohio, a long levee of small quantity per lineal foot was built by a wheel scraper outfit. The total length of this levee is 9,100 ft.; the maximum height for 2,200 ft. was $3\frac{1}{2}$ ft., and part of the remaining length was combined with a road elevation. Practically all of this work was handled from a borrow pit alongside the levee. The top soil was stripped from this pit and was put aside for use in top-dressing the levee. The main levee fill was made of a mixture of gravel, clay and loam, the finer material predominating. Compacting was secured by the passage of the teams and scrapers over the fill, and little sprinkling was necessary. In 5 years the shrinkage of this levee was from 1 to $3\frac{1}{3}$ per cent of its height, which varied from 3 to 5 ft. The work was done by contract at a price of 50 cts. per cubic yard (see Chap. II for further details of the organization of this job).

A levee about a mile long and ranging from 4 to 20 ft. in height was built at Middletown, Ohio, by a 70-ton railroad type steam shovel equipped with a boom and bucket for dragline work. Although the boom of this machine had a swing of only 180 deg., it worked very well. The material, amounting to 65,000 cu. yd., was all handled with one throw. Under favorable conditions about 100 ft. of levee, equal to about 1,000 cu. yd., could be thrown up in a 10-hr. day. The contract price of this work (in 1920) was 35 cts. per cubic yard.

Levee Construction by Cableway.—On the Mississippi River a job of enlarging a levee was handled by a tight-line cableway having a span of 662 ft. The towers, which were truck mounted to operate on tracks, were of steel construction, 85 and 45 ft. high, respectively. The main cable was of $2\frac{1}{4}$ -in. diameter. A 3-cu. yd. drag bucket did the digging. The bucket was loaded by means of a cable which led from the front end of the bucket to a drum on the main engine, and was lifted by means of a cable which was attached to the bail of the bucket and ran over sheaves to another drum on the main engine. The bucket was dumped by a haul-down rope which pulled down on the dumping line attached to the back of the bucket and ran to the conveying drum, thus accelerating the movement of the rear end of the bucket relatively to that of the front end and consequently caused the back end to lift and dump. This outfit operated with a crew of one foreman, one operator, one helper, one engineman, one fireman, one signalman, eight laborers on the machine and

track, and three laborers and three teamsters on the levee. The output ranged from 13,000 to 28,000 cu. yd. per month. All material was dropped from a height of 10 to 40 ft., thus securing good compaction.¹

Hydraulic-fill Levee with Sand Core.—In the Sacramento Valley, in California, a levee over 17 miles long and averaging 15 ft. in height, was constructed by a combination of dragline and hydraulic dredge plants. The available material for the embankment was sand from the river, and it was desired to construct a levee with greater stability than could be obtained by the use of a pure sand fill. So it was decided to excavate a cutoff or core trench along the line of the levee and to throw the excavated material out to each side to form dikes; then the trench could be filled with sand from the river, and the material at the toes pulled up over the sand fill.

Dragline excavators, truck mounted, and equipped with 100-ft. booms and $3\frac{1}{2}$ - to $4\frac{1}{2}$ -cu. yd. buckets, were used to excavate the cutoff trench. This trench was of sufficient size to furnish enough material for the side dikes. The trench sides were cut to 1 to 1 slopes. The top of the dikes was kept about 6 ft. below the finished top of the levee, and was 5 ft. wide; the slopes of the dikes were $1\frac{1}{2}$ to 1.

The sand fill was made by a 20-in. hydraulic dredge on a hull 150 by 35 by 9 ft., which operated downstream in the river about 150 ft. from the levee. The digging averaged from 18 to 32 ft. in depth. The average length of discharge pipe was about 1,400 ft., with a lift of from 20 to 30 ft. The pipe line was laid on a trestle built in the trench, and sections of window pipe were used to distribute the material. The window pipe line was about 700 ft. long and was laid with a slight downward grade. Baffle boards were used for a distance below the discharge end of the pipe to prevent scouring of the inside slopes of the dikes. After the fill was brought nearly to grade some of the dike material was pulled up over the sand slopes to cover them. The finished slopes are 2 to 1, and the top is 24 ft. wide.

On this job 1,224,400 cu. yd. of material were handled by the two draglines, and over 2,000,000 cu. yd. were placed by the dredge.²

White River Levee at Indianapolis.—Levees totaling about $4\frac{1}{2}$ miles in length were built along the White River through the city

¹ *Eng. Contr.*, Vol. 45, No. 23, June 7, 1916.

² *Eng. Contr.*, Apr. 29, 1914.

of Indianapolis to afford protection from floods. These levees were built with wide tops in order that a boulevard might traverse them. The top width averages about 75 ft. for one portion and 60 ft. for the lower section. The top grade is from 12 to 17 ft. above the original ground level and slopes are $2\frac{1}{2}$ to 1 on the river side and $1\frac{1}{2}$ to 1 on the land side. The river slope is paved with concrete. The embankment material is practically all gravel excavated from low ground along the river side of the levees, but no borrow pits were allowed to extend below low water level.

The area for the base of the levees was cleared and grubbed and then deeply plowed to insure a good bond.

The upper section of the levee system was handled by an electric dragline excavator equipped with a 100-ft. boom and $4\frac{1}{2}$ -cu. yd. bucket, mounted on four-wheel trucks traveling on two tracks. The tracks were built in sections with longitudinal timbers under the ties. This portion of the levee was built in two operations. The dragline first traveled along the river bank near the toe of the slope and cast up the main portion of the fill by direct throw. Then the machine was run along the top of this fill, taking material from the slope on the river side and casting it over to the land side.

At the lower end of the same contract a 70-ton steam shovel was used. It loaded into 4-cu. yd. dump cars, which were hauled in 10-car trains by steam dinkey locomotives operating on $3\frac{1}{2}$ -ft. gage track. A small steam dragline, equipped with a 75-ft. boom and $1\frac{1}{2}$ -cu. yd. bucket, traveled on top of the fill and dressed the river slope for the concrete facing. A spreader car was used to level off the fill after material was dumped.

On another portion of the work a 70-ton steam shovel served by three trains of 4-cu. yd., four-wheel dump cars of $3\frac{1}{2}$ -ft. gage handled the fill. Part of this work was along an old levee and behind concrete walls for a subway. The material was spread and leveled by teams and drag scrapers. On this section about 3 miles of track were used, all of 60-lb. rails.

The lower end of the job was handled by a walking dragline with a 60 or 75-ft. boom and $1\frac{1}{2}$ - or $2\frac{1}{2}$ -cu. yd. bucket. This entire fill was made by the dragline from the ground level. The machine ran first along the edge of the borrow pit, and then made a second run close to the toe of the fill, scraping the river

slope to proper line and grade and casting the material in the rear of the first fill.

All of the above work was carried on in two 10-hr. shifts per day. It was all contract work.¹

Levee Constructed by Slackline Cableway.—A slackline cableway outfit was used for levee enlargement along the Mississippi River. The span was about 450 ft. The head tower operated on tracks along the banquette (or back fill) of the old levee, and the tail tower traveled parallel to it on the opposite side of the borrow pit, which was behind the levee. An 8-cu. yd. drag bucket was used. The crew on this outfit consisted of two foremen and riggers, two head tower operators, one tail tower operator, one oiler, one fireman, ten laborers, trackmen and levee dressers, and one team and teamster. Work was carried on in two 10-hr. shifts. On this job the fill required was about 1,800 cu. yd. per 100 lin. ft. of levee. The average output per month was about 30,000 cu. yd.²

ROADBED EMBANKMENTS

Embankments for either highway or railway roadbeds differ from levees in several respects. First, roadbed embankments usually need not be impervious; second, they are often constructed through rough country where cuts and fills alternate frequently and the length of the fills is not extremely great; third, they may be very high fills; fourth, they usually have no physical relation to streams, that is, they do not follow water courses; and, fifth, the construction of roadbed embankments is closely tied up with the excavation operations on the project.

All of these factors influence the methods of handling roadbed embankments and the selection of equipment and plant for a given job. On the usual highway or railroad grading job the placing of embankments is secondary to the excavation; in other words, planting of the job is considered from the standpoint of the amount, nature and location of material to be excavated, and embankment construction is handled by the best means possible with the plant at hand. Therefore, beyond pointing out some of the essential requirements to secure a satisfactory fill, little need be said here about roadbed embankment construction methods, as detailed discussion of plant and methods for

¹ *Eng. News*, Vol. 74, No. 21, Nov. 18, 1915.

² *Eng. Contr.*, Vol. 45, No. 23, June 7, 1916.

roadbed construction has been given in Part I under the various excavation headings.

On highway roadbed construction where the grading is light, fills are usually made by direct dumping of the material as it is delivered to the site. When teams and scrapers are used or when the material is hauled in in dump wagons the material is spread as dumped by hand and the travel of the teams over the fill compacts it. Sometimes leveling and spreading are done by blade graders. When highway embankments are high, attention should be given to proper compacting, especially if the road-



FIG. 83.—Making railroad fill by dumping from trestle.

The spreader car at the rear is used to spread the material after it reaches the top of the trestle.

way is to be paved after the completion of the grading operations. Modified rolled fill methods are often used to secure embankments that will be stable.

Embankments for railway roadbeds and some large highway fills are nearly always built up by dumping from cars hauled to the site in trains by locomotives; except that on side-hill construction the material is cast over from the cut. Two methods are in common use to build up high fills; (1) dumping from the end of the fill, and (2) dumping from trestles (see Fig. 83). In the first method, the dumping track is raised and extended as the fill grows. A considerable force of laborers is necessary to take

care of track extensions and to jack up the tracks as the fill increases in height.

When timber is available at or near the job, trestles are often built out across the ground to be filled (see Fig. 84). The trestles may be built to the full height of the fill, or may extend only part way up. In the latter case, when the fill reaches the top of the trestle, additional lifts are made by jacking up the dumping track (see Fig. 85). Since most of the timber in the trestle must be left in the fill, consideration must be given to the cost



FIG. 84.—Trestle for large railroad fill.

of procuring the timber as well as the expense involved in the construction of the trestle. Another factor that must be considered when trestle construction is used is that, especially in high fills, there is always a chance that the trestle will be damaged by large rocks or chunks of material falling against the bents as the material is dumped. Damage also may occur to the trestle due to subsidence of the original ground as the weight of the fill increases. In spite of these possible disadvantages, trestle construction is often more economical than any other method for handling high fills. The principal savings are in labor and time. Once a trestle is built practically no labor will be necessary on the dump until the fill has reached practically full height.

Since most high railway roadbed fills are made by dumping, with no rolling or other means of compacting the material, special allowance must be made for settlement or shrinkage. Settlement may occur from one or both of the following causes: (1) shrinkage of the material as it is compacted by weather and superimposed loads, and (2) subsidence of the original ground under the fill, allowing the entire structure to settle. It is an easy matter to provide for the first contingency, but subsidence cannot be forecast or controlled so easily where foundation conditions are questionable. It is well to make a few test borings or, better, sink test pits over the area to be filled before any work is



FIG. 85.—Dumping material on railroad fill.

The trestle is covered up and the track must be jacked up as additional lifts are made.

started. The results of such borings or test pit observations may influence very considerably the subsequent work. Sometimes an entire relocation of the line will be deemed advisable.

A method sometimes used in making high fills is to substitute for the trestle a suspension cable arrangement across the gap to be filled. This scheme was used successfully at the Taylorsville dam, across the Miami River above Dayton, Ohio. It was necessary to build a rock-fill dike or cofferdam across the old channel of the river, the maximum height of fill being about 30 ft. above the river bed and 20 ft. above low water level. Trestle construction would have been expensive and subject to damage, if not entire loss, by high water during the construction of the fill.

Also, it was desirable to leave no timber in the structure. Four $1\frac{3}{8}$ -in. steel cables, about 4 ft. apart, were stretched across the gap, which was about 400 ft. wide. The cables were securely anchored to deadmen on each side. Then 14-ft. wood ties were laid on the cables on 6-ft. centers and fastened to them by $\frac{3}{4}$ -in. hooked bolts. Two regular 5-ft. ties were placed between each pair of long ties. Rails were spiked to the ties in the usual



FIG. 86.—Dumping from suspension-cable bridge.

Four $1\frac{3}{8}$ -in. cables were used, with 14-ft. spreader ties spaced on 6-ft. centers and regular ties between the spreader ties. The trestle in the background carried a pipe line, and had no connection with the suspended cable structure.

manner. The hauling equipment consisted of trains of 4-cu. yd. side dump cars hauled by 18-ton steam dinkeys on 36-in. gage track. Trains were backed on to the swinging track, each car being dumped as it reached the end of the fill. Thus the track had to bear only the weight of one loaded car at a time and the locomotives never got on the structure. Two dinkeys had to be used, as the sag in the cables was so great when the load came on that one dinkey could not hold the train (Fig. 86).

CHAPTER XII

ROLLED EMBANKMENTS

The construction of embankments of the rolled-fill type is fairly well standardized as to general methods, though the details of carrying out the work must necessarily vary according to conditions surrounding a particular job. Rolled-fill embankments have been built for various purposes, but usually they are dams for the storage of water. Recently this type of construction has been employed for several large stadiums and for oil-storage reservoirs.

As the purpose of this discussion is to outline construction methods, no consideration will be given here to the design or selection of sites for rolled-fill dams except as they affect the methods of carrying out the building of the structures. The following discussion will outline the general considerations involved in rolled-fill dam construction, and will be followed by descriptions of actual construction methods on several projects on which somewhat varying methods were used.

Rolled-fill embankments which are to be used for other purposes than to impound water are constructed in much the same manner as dams, except that cutoff trenches or walls will not be necessary, nor will it be required to take as much care in sealing the layers of material as deposited.

FOUNDATIONS AND PREPARATION OF SURFACE

When the embankment is to be constructed for water storage it is essential that it be impervious, and provision must be made to prevent any seepage under or through the structure. It is customary to dig a cutoff trench along the long axis of the dam and at or near the center line. This trench is then filled with suitable material, and sometimes a concrete wall is built in the bottom of the trench to further provide against seepage. The cutoff trench should extend down to an impervious foundation of solid rock, hardpan, or safe, firm material which is watertight. The trench is often backfilled with puddled material.

The foundation for the embankment or dam should be plowed up and stripped of all vegetable growth, trees, roots, sod, top soil, etc. Large, loose stones also should be removed. The vegetable matter may be worked into piles and burned, but it is safer to remove this material beyond the toe lines of the embankment. The ground is then thoroughly scarified so that the bottom layer of embankment material will bond with it.

The soil stripping operations may be handled to advantage by elevating graders where the ground is not rough and timbered. Other methods of foundation preparation are by the use of plows, blade graders, or scrapers of the slip, fresno, or wheeler type. The principal factors which determine the method to be used in preparing the foundation are (1) the size of the job, *i.e.*, the area of surface to be prepared, and (2) the availability of equipment. Often the equipment which will be employed to construct the fill may be used to prepare the foundation.

Care must be exercised to see that the foundation is properly prepared for the embankment and the specifications should be strictly adhered to on this very important part of the work, as the stability of the structure will depend largely on the sealing of the foundation.

EMBANKMENT CONSTRUCTION

It should be remembered that a dam must be capable not only of sustaining a load, but also must be so constructed that it will be watertight. The methods of handling and depositing the material in rolled fill dams are equally as important as the material selected for the fill.

First, a supply of water will be necessary, as dry material cannot be properly compacted. In rainy weather, of course, the soil will probably be wet enough; in fact, one of the drawbacks in rolled-fill work is that quite frequently operations must be suspended during rainy spells because of difficulty in working the wet material. This is so especially in clayey soils, and should be considered when planning a job, as much time may be lost during a rainy season.

The usual procedure is to haul in and spread the material on the previously prepared foundation in layers of as near uniform thickness as possible; then to sprinkle the fill, if necessary, and thoroughly roll the layers. The surface of each layer should be

roughened by disc harrows or other means after rolling and before the next layer of material is brought in.

When the dam is to be constructed entirely of rolled fill, it will be well to distribute the material so that the finer and more impervious part of it will be on the upstream side of the dam.

Specifications vary as to the thickness of the layers of material; the limits range from about 4 to 10 in., and 6 in. is the common requirement. That is, the thickness of the layers should not exceed 6 in. after rolling. If the material is spread loose in layers of excessive thickness the ordinary rollers will not thoroughly compact the fill, and the result will be a series of layers, each well compacted on top but loose near the bottom.

It is customary to make the layers as nearly level as possible in a direction along the dam, and sometimes specifications provide that the layers shall be horizontal. Others provide for a slight slope either toward or away from the center of the embankment. This sloping construction may tend to prevent percolation, but if the layers are laid horizontal and are properly bonded and compacted, there will be no stratification which would permit percolation. Under no circumstances should the slope of the layers exceed about 10 to 1.

Various means are used to convey the material to the dam. If the borrow pit is close by so that the haul is short, teams and scrapers may be employed. The fresno is a favored scraper for this kind of work. Elevating graders and wagons may be the plant for loading, hauling, and unloading the material. On very large jobs, and where the haul is long, trains of dump cars hauled by steam or gasoline locomotives or teams may be used. On some recent work motor trucks hauled and dumped the fill.

If the material is hauled on to the embankment by teams and wagons or scrapers, a certain amount of mixing and compacting is secured by the trampling of the stock and the passage of the wagons or scrapers. When dump cars are used to convey the material, the only preliminary compacting is that of the teams or tractors hauling the leveler or grader that is used to spread the material.

As the material is dumped and while it is being spread all large stones should be removed. It is customary to require the removal of all stones over 5 in. in longest dimension. The stones picked out of the fill are usually saved for riprap or paving which is often placed on the surface slopes of the structure.

Spreading of the dumped material is accomplished by the use of blade road graders, or sometimes by home-made devices of various kinds. In light material harrows are frequently used for spreading and breaking up clods. Four- or six-horse road graders are commonly used for the leveling and spreading process. When the fill is dry, water is applied as needed from hose or from sprinkler wagons. Usually the wetting is done as the material is being spread and before rolling. In very dry conditions the top of each layer should be wet before any material is dumped on it. The wetting should be done in a manner which avoids the formation of pools of water, which means that the hose or sprinkling wagon should be handled by an intelligent man who knows how to properly distribute the water.

Rolling and compacting of the fill should preferably be done by steam rollers or traction engines, though horse-drawn rollers have been used on small jobs where the material was light and was spread in thin layers. The rolls of the compacting machine should be grooved, banded, or corrugated so that the rolls will cut into the material and mix as well as compact it. It is a good plan to allow the loaded dump wagons which haul in the material (if wagons are used) to drive over the spread material, as the wheels dig in and mix the layers. Many specifications require that the rollers or traction engines used shall weigh at least 12 tons, and shall have three wheels.

Rolling should be thorough; the rollers should work both longitudinally and transversely on the fill. The number of impressions necessary will depend much on the nature of the material, the degree of moisture, and the thickness of the layers. The object is to secure a fill as homogeneous as possible.

Following the placing of the rolled fill, the upstream slopes of dams are usually surfaced or paved with stone riprap, concrete, or other material to protect the slopes from erosion due to wave action on the reservoir surface.

EXAMPLES OF ROLLED-FILL EMBANKMENT CONSTRUCTION

Keechelus Dam.—This structure was built by the U. S. Reclamation Service on the Yakima River, in Washington. It is an earth and gravel embankment about 6,500 ft. long along the crest, and 20 ft. wide on top. Its height above the original river bed at the river section is 70 ft. The slopes are 3 to 1 on

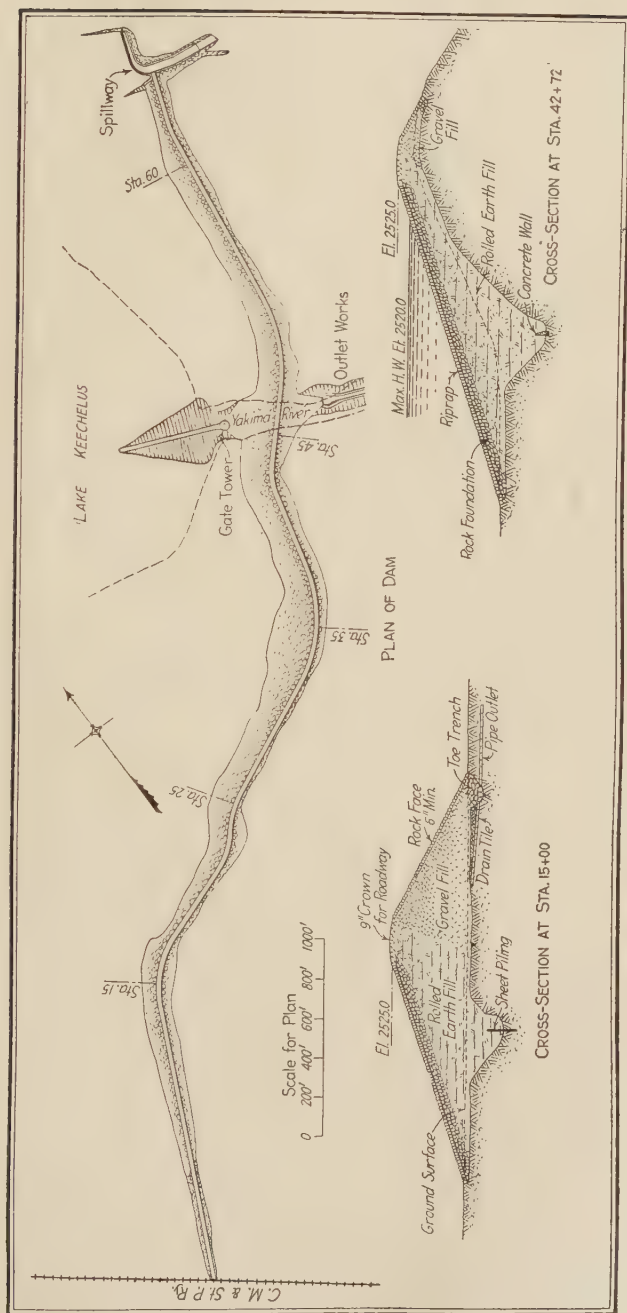


FIG. 87.—Plan and typical cross-sections of Keechelus dam.

This rolled fill dam is 6,500 ft. long and 20 ft. wide on top. Its height above the original river bed at the river section is 70 ft. (From *Eng. Record*, Vol. 74, No. 16.)

the upstream side and 2 to 1 on the downstream face (see Fig. 87). A cutoff trench 10 ft. wide at the bottom and from 5 to 20 ft. deep was dug; at the river section a concrete core wall was placed in this trench and it was puddled in by hand with earth to a depth of about 2 ft. above the top of the wall. At one end of the dam 9- by 12-in. timber piling was driven to serve as a core wall through a stretch of water-bearing gravel.

After the site was cleared, all stumps over 12-in. in diameter were grubbed out and removed. Then a 2-ft. layer of top soil was loosened by plows and removed by slip and fresno scrapers. The cutoff trench was excavated by a $1\frac{1}{2}$ -cu. yd. steam dragline.

The main embankment, containing 522,000 cu. yd., is of combined construction, rolled earth fill for the central and upstream part and gravel fill on the lower side. The gravel fill was dumped, spread and rolled on the higher sections, while the low fills were dumped directly in place. On fills exceeding 20 ft. in height a 12-in. tile drain with open joints was placed in the gravel section, with outlet drains to the toe trench at all low points.

A 2-ft. gage railroad extended the entire length of the dam and all material was hauled in on trains of $2\frac{1}{2}$ -cu. yd. dump cars hauled by 9-ton steam dinkeys. The fine material which formed the watertight portion of the structure was spread by fresnos in 6- to 8-in. layers, sprinkled thoroughly, and given not less than six rollings with a 12-ton traction engine. The rolling was done in two directions in order to avoid a tendency to continuous jointing in horizontal planes. The traction engine gave about 300-lb. pressure per square inch of tread of the two rear wheels.

Material for the river section was hauled in on the lower elevations by 2 cu. yd., three-horse dump wagons, dumped where needed and spread by fresnos.

Before the material was rolled all stones over $4\frac{1}{2}$ in. in longest dimension were removed.

Test pits were dug as the embankment was being placed, and the sides of the pits were examined for stratification, cleavage, moisture, etc. Then the holes were filled with water and the seepage observed. Mechanical analyses and silt tests were made of materials obtained from the test pits. A satisfactory embankment was obtained by the methods employed on this job.¹

¹ *Eng. Record*, Vol. 74, Nos. 16 and 18, Oct. 14 and 28, 1916.

Deer Flat Embankment.—The lower embankment of this project in Idaho was constructed by the U. S. Reclamation Service some years ago. This fill, which is about 7,000 ft. long and contains 617,915 cu. yd., is also of combined construction, and two methods of obtaining and hauling the material were used.

Material for the earth body of the fill was hauled mostly from borrow pits above and below the dam and extending parallel to it for its entire length. This material as it lay in the borrow pits, was a sandy loam containing some clay underlain with a hardpan containing a large percentage of clay. The upper layer averaged about 18 in. in thickness. The outfit that handled this material consisted of three elevating graders, two 22-hp. traction engines and 40 three-horse dump wagons. Two graders were in use all the time, each drawn by a traction engine or by 16 to 18 horses. The borrow pits, the depth of which averaged 1.3 and 3.5 ft. respectively, were wet down frequently, both to keep down the dust and to loosen up the hardpan. These pits averaged 500 ft. in width, and a 40-ft. berm was left between each of them and the respective toes of the dam. The haul averaged from 400 to 500 ft. Under favorable conditions the output of the graders was from 575 to 725 cu. yd. per day.

To spread the material as it was dumped from the wagons, two four-horse road graders were used. Water for sprinkling was pumped from a small reservoir located on the upper berm and supplied from an irrigation ditch nearby. Four 800-gal. sprinkler wagons were used, each drawn by four horses. The amount of water used represented about 12 to 16 per cent of the volume of the material to which it was applied.

Rolling was done by two "home-made" concrete rollers, each about 5 ft. long and weighing a little over 1 ton per lineal foot of tread. Each roller was drawn by four horses.

The part of the work described above totalled 586,278 cu. yd., the unit cost of which was distributed as follows:

Item	Cost per cubic yard, cents	Per cent of total
Excavating.....	3.67	18.5
Hauling.....	7.83	39.7
Spreading.....	0.83	4.2
Sprinkling.....	1.22	6.2
Rolling.....	0.33	1.6
Freight on equipment.....	0.84	4.3
Drainage.....	0.35	1.7
Clearing right of way.....	0.13	0.7
Superintendence.....	0.83	4.2
Repairs.....	0.80	4.2
Interest on investment.....	1.14	5.8
Depreciation.....	1.76	8.9
Total.....	19.73	100.0

The above work was all done prior to 1912.

The gravel and coarser material for the downstream side of the dam was excavated by three steam shovels equipped with 2-cu. yd. dippers, loading into 3- and 4-cu. yd. dump cars and hauled by 14-ton steam dinkey locomotives. The average haul was 3,600 ft. After a trainload of this material was dumped the track was thrown over 10 to 12 ft., and the earth was spread, sprinkled, and rolled as described above. The layers of spread material were 8 in. thick before compacting.

The steam shovels and cars moved 85,637 cu. yd. into the embankment, which cost 30.68 cts. per cubic yard, distributed as follows:

Item	Cost per cubic yard, cents	Per cent of total
Excavating.....	8.27	27.0
Hauling.....	9.13	29.8
Spreading.....	1.06	3.5
Sprinkling.....	1.68	5.4
Rolling.....	0.34	1.1
Freight.....	0.59	1.9
Superintendence.....	1.49	4.9
Repairs.....	2.22	7.2
Interest on investment.....	1.16	3.8
Depreciation.....	4.74	15.4
Total.....	30.68	100.0

The above information was obtained from the records of the U. S. Reclamation Service, and was abstracted from *Bull.* 249, Part 1, U. S. Department of Agriculture, entitled "Earth Fill Dams and Hydraulic Fill Dams," by Samuel Fortier and F. L. Bixby.

Miami Conservancy District Dams.—While these five dams were constructed by the hydraulic-fill process (see Chap. XIII),



FIG. 88.—Dragline placing material for rolled fill cross-dam.

The material was handled from a stock pile into the fill. Spreading was done by a drag scraper outfit, and a 12-ton tractor rolled the material.

rolled fill in fairly large quantities was used for one purpose or another at three of them. Most of this rolled fill was placed in cross-dams which were placed at the ends of sections of hydraulic fill. The dams had to be built in sections because it was not possible, in one season, to bring them up to a height sufficient to turn a maximum flood through the conduits, and provision had to be made for safely handling possible high water. The cross dams had to be very carefully constructed as each became a part of the permanent structure. Obviously they could not be built by hydraulic-fill methods, but the selection and compacting of

material in them must be so handled that they would become an integral part of the whole structure, without introducing elements of weakness due to settlement or to lack of water tightness.

Standard methods for constructing rolled fill were used. The material was usually obtained from the same borrow pit that furnished hydraulic-fill material, except at Taylorsville, where a separate pit was used. Care was taken to exclude all rock over 5 in. in diameter. Dragline machines excavated the material at each dam and it was conveyed to the embankment either in



FIG. 89.—Starting a rolled-fill cross-dam.

Here the material was hauled in wagons and spread by hand. The tractor compacted the material.

dump-car trains or wagons, except at Englewood, where a dragline machine rehandled the material directly to the fill from a stock pile (see Fig. 88).

The material was spread by horse-drawn graders into 6-in. layers, and, if not sufficiently damp, was sprinkled by hose or watering wagon. The layers were kept as nearly level as possible.

Both steam rollers and traction engines were used for rolling; a 12-ton machine was the minimum size used (Fig. 89). Rolling was carried on in both directions, along and across the fills.

One of the factors which had a definite effect on the cost of this type of work was that it was interrupted so much by rainy weather in the course of a working season. Not only would the work have to be shut down during a heavy rain, but it was necessary to continue the shut-down for a day or two after the rain had stopped, until the material had dried out sufficiently so that the spreading and rolling could be resumed. Work on the hydraulic fills could be continued without interruption regardless of rainy weather, but in this part of the country the necessary interruptions to a rolled fill on this account must be taken into consideration.

Following are cost figures on more than 100,000 cu. yd. of rolled fill, which were placed at Englewood, Taylorsville, and Huffman dams. The cost of coal is included under "Supplies." At Englewood an electric dragline machine was used to place a

COSTS OF ROLLED EMBANKMENT AT ENGLEWOOD, TAYLORSVILLE, AND HUFFMAN DAMS

		Unit cost, cents per cubic yard	Per cent of total
Englewood Dam, 93,900 cu. yd.			
Superintendence and overhead.....	\$ 4,467.91	4.8	5.0
Labor.....	57,466.22	61.2	63.3
Supplies.....	9,974.83	10.6	11.0
Power.....	2,281.92	2.4	2.5
Plant depreciation.....	16,502.14	17.6	18.2
Total.....	\$90,693.02	96.6	
Taylorsville Dam, 15,200 cu. yd.			
Superintendence and overhead.....	638.00	4.2	4.1
Labor.....	6,826.60	44.9	43.5
Supplies.....	7,935.05	52.0	50.4
Plant depreciation.....	310.00	2.1	2.0
Total.....	\$15,709.65	\$1.032	
Huffman Dam, 14,450 cu. yd.			
Superintendence and overhead.....	\$ 605.29	4.1	4.3
Labor.....	12,534.31	86.8	90.9
Supplies.....	551.12	3.8	4.0
Plant depreciation.....	122.64	0.8	0.8
Total.....	\$13,813.36	95.5	

large part of the material in the fill from where the cars dumped it, and the cost of electric power is shown as an item. At the other dams no electric power was used on this item of work. At Taylorsville a steam dragline and a steam roller were used, making the cost of supplies high, as that item includes the cost of coal. At Huffinan most of this work was done with teams, some by contract, making the "Labor" item high, and the "Supplies" and "Depreciation" items low.

During the period of this construction, labor was being paid from 40 to 46 cts. per hour, dragline operators from \$200 to \$278 per month, locomotive runners 50 to 60 cts. per hour, firemen 40 to 56 cts. per hour, brakemen 40 to 56 cts. per hour, oilers 40 to 56 cts. per hour, all men on an hourly rate being given 11 hr. pay for 10 hr. work (time and a half after 8 hr). While these cost figures are high, due to the high prices prevailing at the time the work was done, it is believed that they afford a fair basis for comparison as to relative cost of rolled fill and hydraulic fill as the latter type was carried on at the same time on the same jobs (see Chap. XIII for hydraulic fill costs).

Reconstruction of Part of Calaveras Dam.—The Calaveras dam was built by the Spring Valley Water Company in California. Originally it was a hydraulic-fill structure part of which failed by slipping out. The plans for reconstruction provided for a dry fill to replace the section of the original structure which had failed. The central portion is of clay rolled in layers connected to a 10-ft. cutoff, with a section gradually tapering from a top width of 100 to 25 ft. The impervious center is supported by a loosely dumped sandstone and shale fill. The upstream slopes are 3 to 1 and on the downstream side the natural slope of $1\frac{1}{3}$ to 1 is maintained.

To have completed the structure by the hydraulic-fill process would have been more expensive than the method adopted as it was necessary to maintain water in the reservoir during the reconstruction. A dredging outfit would be necessary, and as the heads were constantly fluctuating due to changes in the water level, efficient hydraulic operations would have been hard to secure. For the dry-fill material borrow pits were close at hand and easy to get at.

The first operation was the removal of a "clay-pool" deposit which had been trapped near the upstream edge of the dam by the 1918 slide. This material furnished the clay for the per-

manent core and was replaced by coarser material which was to form a foundation for the upstream supporting embankment.

The core material, amounting to 117,420 cu. yd., was hauled to the dam in 4-cu. yd. motor trucks and dumped. It was spread with fresnos, disc harrowed to break up the lumps, and rolled with 12-ton steam rollers. The layers were about 6 in. thick. The average truck load of loose material, amounting to 5 cu. yd., was consolidated to 3.06 cu. yd. by the rolling process.

The supporting embankments were built of shale and soft sandstone excavated from a quarry about 1,500 ft. from the dam, and transported in trains of three to five 12-cu. yd. dump cars hauled by steam dinkey locomotives on standard-gage track. Trestles about 20 ft. high were built across the dam and the material was dumped over the edge until the fill was up to the tops of the trestles. Then this fill was extended in width to meet the rolled center core on the one side and the outer limits of the dam on the other.¹

Rolled-fill Dam in Ohio.—Near Youngstown, Ohio, a dam was constructed to store water for use in the city. This structure was of the rolled-fill type, 2,840 ft. long with a concrete spillway section 638 ft. long. The slopes were 2 to 1 on both sides.

The material for the dam was a mixture of clay and gravel containing a large percentage of clay. Steam shovels excavated this material from the borrow pit which was in the reservoir just upstream from the dam. During the first season teams and wagons were used to haul and dump the material on the fill, but the second season was so rainy that the wagon outfit could not be used as the fill became too soft, so narrow-gage tracks were laid from the borrow pit to the dam and small dump cars were hauled in six-car trains by teams. A snatch team was necessary to get the trains out of the borrow pit. The track was shifted from side to side of the fill as the work progressed.

The material was dumped and spread in 6-in. layers, the surface being wet down when necessary in advance of each new layer. A 10-ton road roller was used to compact the material.

Along the upstream toe of the earth fill a concrete cutoff wall was constructed, extending to solid rock which was from 30 to 36 ft. below the ground surface. The upstream slope was surfaced part of the way up with a layer of concrete, and above this

¹ *Eng. News-Record*, Vol. 96, No. 13.

facing, and extending to the top, 18-in. stone masonry was laid on the slope. The total fill in this dam is 200,000 cu. yd.¹

Rolled-fill Dam in California.—The Tabeaud dam was built in 1901, in Amador County, California, for water storage. It is about 100 ft. high and contains 370,000 cu. yd. of rolled fill. The body of the dam was constructed in 6-in. layers up to a height of 60 ft., and in 8-in. layers above that elevation. The top of the fill was kept basin-shaped during construction, with a slope of about 1 to 25 from the sides toward the center.

The material was clay mixed with gravel and was obtained from a borrow pit about $\frac{1}{4}$ mile from the dam. Excavation was handled by four-horse fresnos, which loaded four-horse dump wagons through a "loading trap." This trap was a platform elevated above the ground with a hole in the floor. Wagons drove under the platform and the loaded fresnos were dumped from above into the wagons. The material was dumped along the dam in rows by the wagons as they moved along, the rows being parallel with the long axis of the dam. Road graders spread the dumped material into 6 or 8-in. layers. Each layer was harrowed to break up clods, sprinkled, and rolled.

Three road graders, each operated by six horses, and two men, spread about 2,000 cu. yd. of material per 10-hr. day. There were two rollers, each operated by six horses and one driver, and two harrows, each operated by four horses and one driver. Water wagons hauled the water for sprinkling.

With labor at \$1.50 and \$2 per day and horses at \$1 per day, the cost of this fill amounted to 39.2 cts. per cubic yard, distributed as follows:

	Cents per Cubic Yard
Plant charge.....	1.0
General expense.....	2.0
Loading and hauling.....	32.3
Spreading.....	1.5
Sprinkling.....	0.8
Harrowing.....	0.6
Rolling.....	0.8
Total.....	39.2

The cost of the equipment, wagons, tools, etc., exclusive of stock, was about \$16,000.

¹ *Eng. Record*, Vol. 74, No. 14.

During three months the output on this job averaged over 2,000 cu. yd. per day or 53,000 cu. yd. per month. The maximum force on the job was 233 men and 416 horses and mules.

The loading and hauling item on this job is relatively high because of the method used. On a job of this size, the excavation could have been done cheaper by elevating graders or steam shovels.¹

Rolled-fill Dam in Nevada.—The Bridgeport dam of the Walker River Irrigation District in western Nevada was constructed by rolled-fill methods. This dam is about 900 ft. long and has a maximum height of about 64 ft., with a 20-ft. top width. The slopes are 3 to 1 on the upstream side and 2 to 1 on the downstream face (see Fig. 90). The site is in the mouth of a canyon, with a very steep slope on one side.

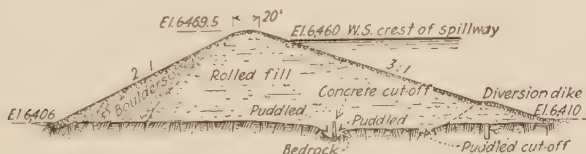


FIG. 90.—Maximum cross-section of Bridgeport dam. (From *Eng. News-Record*, Vol. 98, No. 3.)

Two cutoff trenches were dug, both upstream of the centerline of the dam. One of these was carried to bedrock and a concrete wall was built in it. Both cutoff trenches were filled with puddled material.

The borrow pit from which the embankment was made is in a deposit of sandy, gravelly clay mixed with boulders. A steam shovel with 1-cu. yd. bucket was used to excavate the material, which was hauled to the dam in 2-cu. yd., two-horse dump wagons. An average of 12 wagons was used. The average haul was about 1,000 ft.

The dumps were spaced so that, after spreading and compacting, the layers of material were about 6 in. thick. Boulders in the material were sorted out after the wagons had dumped and were hauled on stone boats to the slopes of the dam, where they were deposited as riprap or rock fill. The finer materials were spread by a small road grader and sprinkled by hose attached to movable pipe lines. Compacting was accomplished both by

¹ U. S. Dept. of Agriculture *Bull.* 249, Part 1.

the travel of the wagons over the fill and by a Fordson tractor which had the rear wheels loaded with concrete. The tractor roller proved a very useful piece of equipment as it could be turned in small space and could cover practically all portions of the fill. It was equipped with a small scraper in front which could be raised and lowered quickly, and which was used in back-filling and leveling work.

Water for the shovel, sprinkling, and other purposes was piped from a small temporary reservoir located just above the borrow pit, the supply being pumped from the river below the dam.

The embankment was placed at an average rate of about 20,000 cu. yd. per month, working one 9-hr. shift per day. The cost of this embankment was 82.8 cts. per cubic yard, including all labor, materials, repairs, depreciation, overhead, etc., in connection with the excavation, hauling, spreading, and rolling of the material. It was estimated that of this 82.8 cts., blasting in the borrow pit cost 8 cts. and separating and placing boulders cost 24 cts.

Settlement records were kept, and at the end of 343 days, the total settlement in per cent of the depth of fill was from 0.15 to 0.62 per cent. as indicated in the following table (Table XVII):

TABLE XVII.—SETTLEMENT OF ROLLED EMBANKMENT OF BRIDGEPORT DAM¹ WALKER RIVER IRRIGATION DISTRICT
(Depths and settlements given in feet)

Station	Depth of fill	Settlement for first 93 days	Settlement for next 250 days	Total settlement 343 days	Total settlement in 343 days in per cent of depth of fill
1	33	0.05	0.00	0.05	0.15
2	62	0.18	0.17	0.35	0.57
3	67	0.17	0.19	0.36	0.54
4	48	0.21	0.09	0.30	0.62
5	33	0.11	0.00	0.11	0.33
6	28	0.07	0.00	0.07	0.25

¹ *Eng. News-Record*, Vol. 98, No. 3, Jan. 20, 1927.

Rolled-fill Construction for Yale Stadium.—This structure, built at Yale University, was constructed by excavating an area

in the center and using the excavated material to build up an embankment around the center, upon which seats were placed. The complete stadium is about 740 by 930 ft. in plan, and 300,000 cu. yd. of excavation and 175,000 cu. yd. of embankment were involved in its construction. The ground level within the stadium is about 27 ft. below the original level, and the top of the embankment is some 27 ft. above the original ground surface. Tunnels provide access to the field and to the seats.

The material was a sandy loam underlain with sandy gravel; the loam layer was about 10 in. thick and was removed from the site. Excavation was handled principally by two slackline cableway excavators, each equipped with 2-cu. yd. buckets. The head towers for these excavators were 85 ft. high and they were mounted on elliptical tracks built around the outside of the structure. The main cable for each outfit was attached at its lower end to a post which was moved about as necessary. A special type of drag bucket was designed which would load easily and also travel up the embankment slope without digging in. Some of the excavation was handled by two $\frac{5}{8}$ -cu. yd. steam shovels, loading into dump wagons.

In building the embankment, the drag buckets made three piles of material between each pair of entrance tunnels; the piles were about 3 ft. high, 8 ft. wide and as long as the width of the bank. These piles were calculated to make, when spread, the 6-in. layers of material desired.

Teams hauling leveling boards leveled off the piles to a uniform depth; the material was then sprinkled with hose, and rolled. Eight impressions were given each layer by the rollers, four by a smooth roller and four by a grooved one, each working alternately. The rollers weighed about 800 lb. per lineal foot of tread, and were drawn by four-horse teams.

On account of the gravelly nature of the material a great deal of water was used, the contract calling for 150 gal. per minute to be run on the bank night and day. Sections of the embankment were dammed off and soaked with water and holes were driven into the fill on 8-ft. centers and water allowed to run in them. The material was so porous that water from a 2-in. hose would disappear into the fill within 5 or 6 ft. from the end of the hose.

When the embankment was nearly to full height, the excess material on the inside slope was dragged up to the top by heavy timber frames operated from the drag scraper towers in the same

manner as a bucket. The frames were about 10 ft. square and were equipped with heavy iron plates projecting below the front edge, so they acted as levelers. Final trimming of the slopes was done by hand.

The outer slope, after trimming by leveling boards and by hand, was covered with about 10 in. of loam, into which strips of turf on 8-ft. centers were imbedded, running parallel to the top of the fill. The purpose was to prevent erosion of the slope from heavy rains until the slope was grassed. The surface of this slope was seeded with a mixture of red top, Kentucky blue grass, and white clover, which gave a quick and satisfactory growth.¹

¹ *Eng. Contr.*, July 19, 1916.

CHAPTER XIII

HYDRAULIC FILL

During recent years, since the construction of hydraulic-fill dams, and similar works by modified hydraulic-fill methods, has become more common over the country, there has been a tendency to speak of any fill in which water is used for sorting or compacting the material, as an "hydraulic fill." Many dams which have been built by semi-hydraulic or puddled-fill methods, have been designated loosely as hydraulic-fill dams. Recently there has been considerable discussion of this matter in the technical press, with the purpose of deciding on suitable definitions to make proper distinction between hydraulic fill, semi-hydraulic fill, and other well-known methods of building embankments. The following definitions are offered as meeting in a general way the ideas which are common in the minds of most engineers who have had to do with the design and construction of hydraulic-fill dams:

Hydraulic-fill Dam.—One in which the materials are brought to the dam and laid down in the embankment by means of flowing water, and manipulated in such manner as to segregate the fines within a predetermined section to form an impervious core.

Semi-hydraulic-fill Dam.—One in which the materials are put into the embankment by some means other than by flowing water, and then worked over or manipulated by means of water in such manner as to separate out and segregate enough of the fines within a predetermined section to form an impervious core.

In this chapter hydraulic fill only will be considered.

GENERAL CONSIDERATIONS

Where the conditions are favorable, hydraulic-fill embankments are preferable to rolled-fill construction, because the selection, transportation, and distribution of the materials are more easily accomplished, greater imperviousness and safety are secured, and the cost will be less. Before a decision is made to use the hydraulic-fill method of construction, however, careful

studies should be made to determine the following points: (1) availability of an ample supply of water, (2) availability of materials of the proper mechanical make-up, (3) location of the materials with reference to the proposed structure. The materials should be preferably a mixture of sand and gravel with enough clay to form an impervious core when the mixture is sluiced in place. The supply of water necessary will vary according to the method of handling the work. If the material is to be sluiced out and pumped to the embankment more water will be needed than if the material is to be excavated by other means and washed down to the embankment in open flumes or troughs. Under the most favorable circumstances the materials suitable for the fill lie above the crest and are obtainable at either end of the proposed structure. It is of further advantage if the water

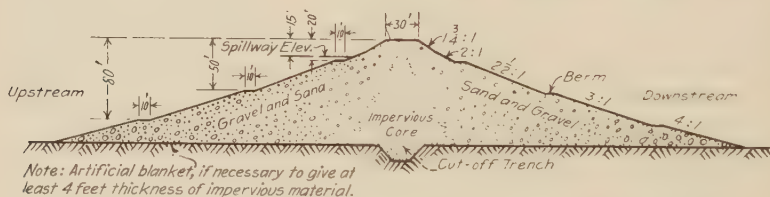


FIG. 91.—Typical cross-section of Miami Conservancy dams.

can be obtained by gravity flow. But such favorable conditions seldom occur, and methods of handling the materials from borrow pit to embankment must be devised to fit the case. The usual methods of depositing material in the fill are (1) directly by flumes or pipes, (2) hydraulicking or hauling to sumps and pumping to the dam, (3) depositing the materials under water confined between two small embankments which are built up as the fill raises. Often a combination of these methods is used.

The construction of hydraulic-fill dams ordinarily involves the following principal problems: (1) stream control during construction, (2) borrow-pit excavation and development, (3) transportation of materials, (4) pump construction and operation, (5) discharge pipe construction, and (6) embankment building. If the conditions are such that the materials may be sluiced directly into the embankment by gravity, the problems are reduced to items 1, 2, 3, and 6 of those enumerated.

As the construction of the five hydraulic-fill dams of the Miami Conservancy District, near Dayton, Ohio, involved most

of the problems that may usually be met with in work of this kind, a detailed discussion of this construction will be given. Structurally these five dams are earthen embankments pierced by outlets of concrete masonry. More than 7,000,000 cu. yd. of true hydraulic fill was placed in these structures. Table XVIII gives the principal dimensions of these dams, and Fig. 91 shows a typical cross-section.

HYDRAULIC FILL AT THE MIAMI CONSERVANCY DISTRICT DAMS

Stream Control.—The control of the rivers at the dams during construction played an important part in hydraulic-fill methods

TABLE XVIII.—PRINCIPAL DIMENSIONS OF MIAMI CONSERVANCY DISTRICT HYDRAULIC-FILL DAMS

	German- town dam	Engle- wood dam	Locking- ton dam	Taylor- ville dam	Huffman dam
Volume earthwork cubic yards.....	800,000	3,600,000	970,000	1,130,000	1,350,000
Maximum height, feet.....	110	125	78	78	73
Length feet.....	1,200	4,700	6,400	3,000	3,300
Maximum thickness at base, feet...	665	785	415	415	380
Volume concrete work, cubic yards...	17,400	26,500	32,000	48,000	37,500

and progress. Until the flood control works were far enough along to give protection, the valley was in constant danger of another disastrous flood. The construction program had to be so arranged that by no possibility would this flood danger be intensified by the conditions existing at any of the jobs during a flood period. Both on this account and as a precaution against damage to uncompleted work, the river closures at the dams had to be so handled that when the closures were once started, they could be carried to a safe height before the next flood season; or if this were not possible, temporary spillways must be provided. The normal flood season in the valley was from January to March, inclusive. While a large flood might occur at other times during the year, it was extremely unlikely that one occurring at other times would be large enough to be disastrous. In planning the construction program, therefore, it was assumed that a flood as great as that of 1913 might occur during January, February, or March, but that at any other time, a maximum flood would not be more than half that size.

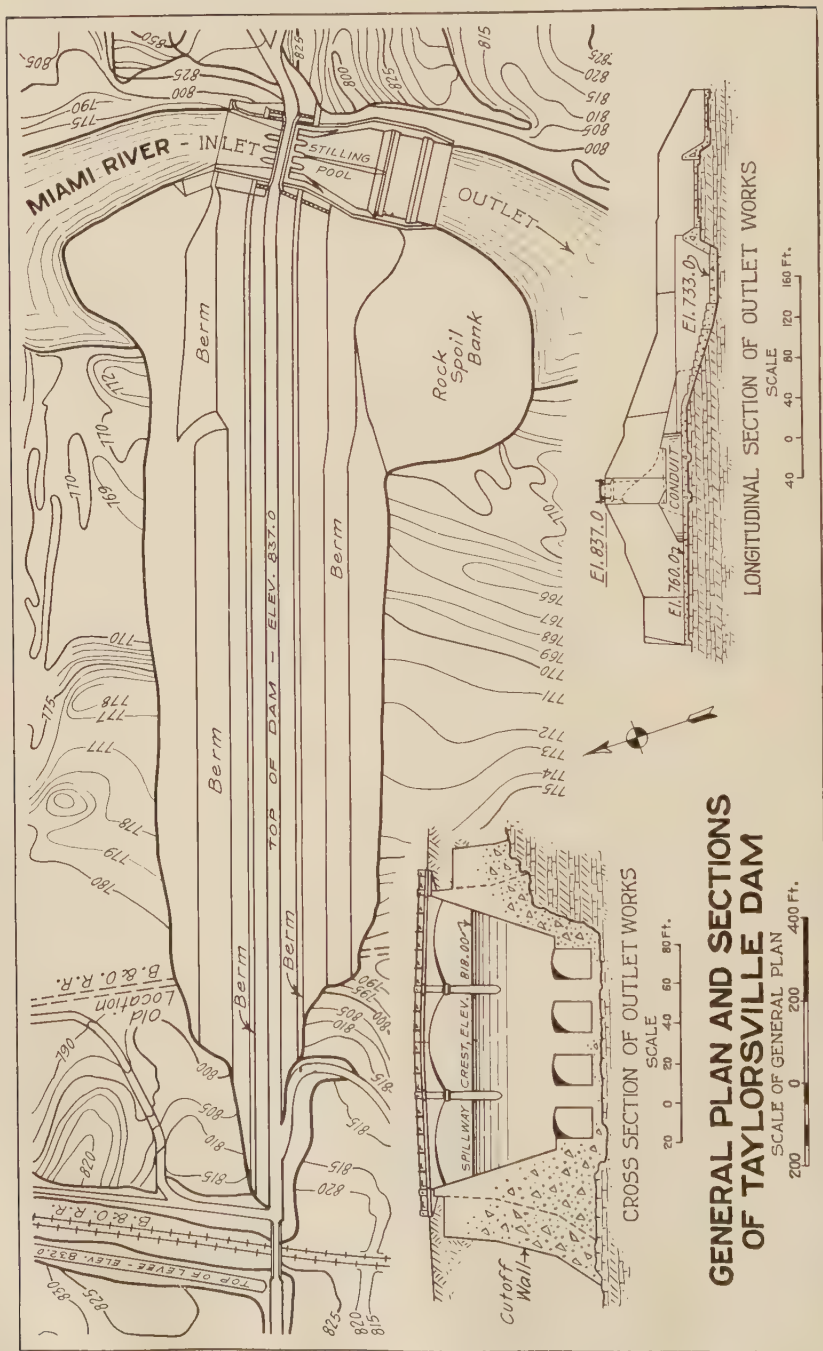


FIG. 92.—General map of Taylorsville dam.
Showing general relation between dam and outlet spillway structure.

At Lockington, Huffman, and Taylorsville dams, where combination outlet and spillway structures were used, the handling of floods during construction was somewhat simplified. The structures at these dams consist of two retaining walls facing each other, with a floor between, forming a concrete-lined gap through the dam embankment. A weir across this gap forms the spillway, and the conduit openings are built through the base of the weir, at river level (see Fig. 92). By postponing the construction of the cross-weir until after the embankment was nearly finished, a gap of large capacity was made available for handling floods during the construction period. At Lockington the outlet structure was located at some distance east of the river channel. Still farther east was a sag in the natural ground which served as a natural temporary spillway. This was left open until the section of embankment to the west of the structure, including the river closure section, had been filled up to a sufficient height prior to the beginning of a flood season. Then, as soon as probability of a dangerous flood had passed for that year, the embankment east of the structure was begun, and both sections were easily brought up to a safe height before the following flood period arrived.

At Taylorsville the situation was complicated by the fact that in the old river bed, where the dam was to cross it, was a deep hole filled with mud and silt. This had to be cofferdammed off and cleaned out before the construction of that section of hydraulic fill could proceed. This increased very considerably the amount of work to be done in the river closure section between flood seasons, and made it essential that the rest of the dam be brought up first to a safe height, leaving as short a section as possible to be put in across the river channel when the time for river closure came. Furthermore, since the excavation for the outlet structure at Taylorsville was suitable for use in the hydraulic-fill embankment, the natural thing to do was to build a section of the fill to one side of the river channel while this excavation was in progress. As the location of the outlet structure was close to one end of the dam, a long section of fill across the valley floor on the other side of the river was built up first, leaving the river gap as narrow as was considered safe, and by this plan it was possible to clean up the bottom of the old river channel, and bring up that section of the hydraulic fill, in

one season, high enough to turn any possible flood through the outlet structure gap.

At Huffman the outlet structure was located so close to the river's edge that a temporary diversion had to be made on that account, so the gap to be closed there included the temporary diversion channel as well as a portion of the original river channel. There, as at Taylorsville, the outlet structure was located at one end of the dam. The volume of embankment was too great to permit its being brought up to safe height all at once, so the section beyond the temporary diversion channel was built up first, and after that had been carried to a safe height, the remain-

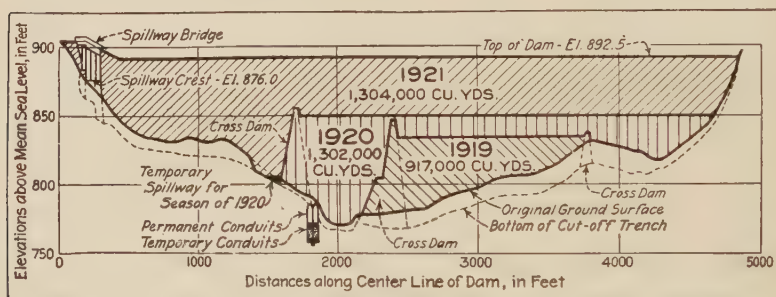


FIG. 93.—Stream control Englewood dam.

This is a longitudinal section of the dam showing the location of the outlet conduits with respect to the river channel, the location of the temporary spillway, and the program of work by years so as to provide safe control of the river during construction.

ing section, making the river closure, was built up during one season.

At Germantown and Englewood, where twin conduits were used, and the embankments are continuous across the valley, stream control was a somewhat more difficult problem. Additional waterway was provided by building the conduits deeper than was required for final capacities, giving them temporarily, for stream-control purposes, more than twice their ultimate size. Even so, a flood like that of 1913 would back up so high behind these openings that a large amount of fill had to be put in to prevent danger of overtopping. At Germantown the valley was narrow, and it was possible to build the required amount of fill during one season. At Englewood, however, the valley was so wide that even though a season's work was as much as 1,000,000

cu. yd., it was not possible to bring up the entire embankment to a safe height between flood periods. Even with a section of embankment brought up to a sufficient height on one side of the river, it still was not possible to close the river section and bring up the rest of the fill in one season. The yardage was too great. Therefore, while the closure of the river channel itself was being made, a temporary spillway was provided to take care of any floods that might occur during that period of the work. The floor of this temporary spillway was about 35 ft. higher than the original river bed, so that the closure of that section, when the time came, was that much easier. Figure 93 is a longitudinal section of the Englewood dam, showing the location of the outlet conduits with respect to the river channel, the location of the temporary spillway, and the sections of embankment placed during three succeeding seasons in order that the river control might be handled safely.

This dividing of the hydraulic-fill embankment into sections required the construction of dams across the ends of those sections, to retain the hydraulic core. These cross-dams needed to be very carefully constructed as each became a permanent part of the completed structure. Obviously they could not be built by hydraulic-fill methods, but the selection and compacting of material in them must be so handled that they would become an integral part of the whole structure, without introducing elements of weakness due to settlement or to lack of water tightness. These cross-dams were built either by puddled fill or rolled fill methods.

Transportation of Materials.—Earth for the hydraulic fill was moved from the borrow pits by three methods: (1) train haulage from pit to sump and then pumping into the embankment, (2) sluicing from pit to sump and then pumping into the embankment, and (3) sluicing direct from pit to embankment. The first method was used at Englewood and the second at Lockington and Taylorsville. At Germantown both the first and second methods were used, and at Huffman all three methods. The methods of obtaining the material from the borrow pits at Englewood, Germantown, and Huffman are described in detail in Chap. V, and the hydraulicking methods used for borrow-pit excavation at Lockington and Taylorsville are outlined in Chap. VII. Data on the costs and method of transporting the borrow-pit materials by trains are given in Chap. IX.

Hog Boxes.—At Germantown, Englewood, and Huffman, where hauling equipment was used, an elongated bin or trough was provided into which the material could be dumped from the cars, and from which it was sluiced to the dredge pump. This structure, called the “hog box,” had a length of about 150 ft., was about 18 to 20 ft. wide at the center and about 15 ft. at the ends. The dumping track came in along one side, at an elevation about 10 to 12 ft. above the bottom of the hog box. There was a small opening controlled by a sliding gate, in the center of the side opposite the dumping track, and through this opening the material was sluiced to revolving screens to take out the over-size, and thence to the pump sump. The floor of the hog box

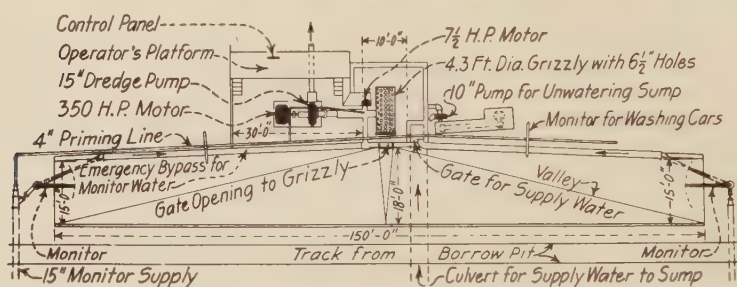


FIG. 94.—Sketch of hog box showing principal dimensions and features of design for a hog box such as was used at Huffman and Germantown dams.

The one at Englewood was similar to these except that it was larger and designed to handle two dredge pumps instead of one.

sloped both longitudinally and transversely towards this opening, the slope from the ends being about 4 per cent, and the transverse slope about 10 per cent. Figure 94 shows the principal dimensions of one of these hog boxes, and its relation to the other features of the hydraulic plant.

It was here that storage was provided for the material coming from the borrow pits, and an opportunity was given of feeding this material at a uniform rate to the dredge pump. The material was washed from the hog box to the pump by means of small giants working at about 50-to 60-lb. pressure. This gave the opportunity of thoroughly breaking up the material and mixing it with the water before it reached the pump sump. There was also the chance here to work out to one side large boulders or lumps of clay which might cause trouble farther along the line.

The storage provided at the hog box was usually about an hour's run for the borrow pit equipment or the dredge pumps, so that if an interruption occurred at either place the other end of the work could go on.

The structure illustrated in Fig. 94 is representative of the hog box installation at Germantown and Huffman. At Englewood, however, where duplicate equipment was used throughout, the hog box structure was larger; it was divided in the center by a partition, and had two openings in the corners, one on either side of the center partition, where the material was fed to the two dredge pumps.

The floors and sides of the hog boxes were of concrete. The floor thickness was usually about 12 in., the bottom 8 in. of which was a very lean mixture. The wearing surface, about 4 in. thick, was made of rich concrete and was carefully troweled off to grade. It was also necessary to put a rich wearing surface on the exposed face of the wall forming the side of the box opposite the dumping track, as impact from flying pebbles caused constant wear. The wearing surface on the floor would take care of about 400,000 to 600,000 cu. yd. of material, after which it would need replacing. In one section of the hog box floor at Huffman, while it was being repaired, hard 12- to 15-in. boulders having one flat face were selected and laid in mortar with the flat side up. The mortar between the stones wore down about 1 in. in a short time, but from that time on there was no noticeable wear. This section was fully as efficient as the rest of the floor and undoubtedly much more durable.

For sluicing the material from the hog boxes, small giants were located at each end; usually not more than one of them was used at the same time, except at Englewood, where duplicate equipment was used. The material coming in on the cars was fairly well broken up, but the action of the giant was beneficial in helping to complete the process. Usually a 2½-in. nozzle with 50- to 60-lb. pressure was found most economical. Occasionally when a hard chunk of clay was encountered it was an advantage to increase the pressure. It was necessary that the feed to the dredge pumps be fairly uniform in order to provide for a reasonably uniform operation of the pumps themselves, and therefore the process of sluicing from the hog box was one requiring some skill and could not be handled in haphazard fashion. It was found best, usually, to play the stream along the toe of the

material, so as to keep a regular amount moving toward the opening, and to prevent the sliding or sloughing of a large mass at one time.

Oversize Rock Screen.—At all of the dredge-pump sumps it was necessary to screen out the oversize rock or large chunks of clay which were too large to pass through the pump and discharge line, or which, by nesting together, might cause trouble in the suction. While much larger stones could be handled by the pumps if they came along one at a time, it was found best to reject from the sump all stones which would not go through a 7-in. opening. One thing that contributed to this decision was the fact that at all the dams a considerable amount of riprapping and paving was specified. The supply of suitable material was limited, and all the oversize rocks rejected at the sump were suitable for this purpose.

The first installations for the screening out of this oversize, were sloping grizzly bars over which the discharge from the hog boxes or from the ground sluices was passed. The rocks and lumps held on these grizzlies were thrown out by hand. This method was crude, and required the continuous services of two or three men to keep the bars clear. A movable self-cleaning grizzly was worked out at one of the dams, and worked very well except that the wear on sprockets and chains was very severe because of the grit in the water, from which it was almost impossible to protect them. The arrangement finally adopted at most places, was a revolving cylindrical screen about $4\frac{1}{2}$ ft. in diameter and 9 or 10 ft. long, made of $\frac{3}{8}$ -in. boiler plate and perforated with $6\frac{1}{2}$ -in. circular openings spaced so as to give about 3 in. of metal between the holes. This screen was suspended over the sump, with its receiving end at the discharge opening from the hog box. It was connected through a jack shaft and belts to a $7\frac{1}{2}$ -hp. motor, and was geared down so as to revolve at a speed of seven revolutions per minute. The barrel of the screen was set on an incline of about $\frac{1}{2}$ in. per foot. Everything dropped through the screen into the sump except the oversize material, which was discharged through the open end into buckets or cars, by means of which it was taken to storage piles, or direct to the riprapping or paving jobs. One man at the discharge end of the screen looked after the loading and taking away of the buckets or cars, and at the same time watched for clay lumps coming through, which he cut up with a shovel and threw back into the

sump. In this way it was usually possible to keep the rock free from foreign matter and suitable for use as paving, without re-sorting. During periods when the clay came too fast to be thrown out in this way, a second man would be put on to help, or the rejections from the screen could be wasted until the material became reasonably clean again.

It was found that one of these revolving screens would pass approximately 500,000 cu. yd. of material, after which time the holes at the upper end would be worn to an extent that repairs were necessary. These repairs were made by putting another lap of boiler plate around the worn part of the screen and cutting new holes of the proper size. The holes were cut with an acetylene torch very quickly and inexpensively.

Incidentally, these revolving screens had some effect of equalizing the flow of material into the sump, that is, in preventing large masses from going in all at once. They also had the beneficial effect of further separating the material into its component parts, making it that much easier to handle in the sump and through the dredge pumps.

Sump.—At the first dredge-pump installations, the sump was simply a concrete-lined pit with a hopper-shaped bottom. The pump foundation was several feet above the normal water surface of the sump, and the suction line extended nearly to the bottom. While such installations had been common practice up to that time, there were a number of objections, the overcoming of which would result in much more economical work. One objection was that the solid material in the sump had a tendency to pile up to the point of instability, and then suddenly slough down, burying the end of the suction pipe and often resulting in plugging it. When this happened pumping operations had to be shut down until the suction line could be dug out and the plug removed. The sump being below ground level, with no chance for drainage, this was not a simple operation.

Again, the suction was not efficient. The loss of head in the suction pipe was very high due to the character of material being handled, the necessary length of pipe, and the unavoidable bend in the line to the pump. In many cases the actual suction lift was only about one-third the total loss of head between sump and pump. Consequently some study was given to sump conditions, and at later installations where the conditions made it feasible, a revised sump design was used which eliminated most of the

objections mentioned. First, the sump was elevated enough so that it could be drained and cleaned out from the bottom; second, the pumps were set in an adjacent chamber, with a waterproof wall between, and low enough so that the suction entrance to the pump was on a level with the bottom of the sump. A short length of pipe through the wall was all that was required for a suction line. There were no bends in it, and the receiving end was in the shape of a bellmouth to further improve its efficiency. The low-pressure water (in addition to that furnished by the

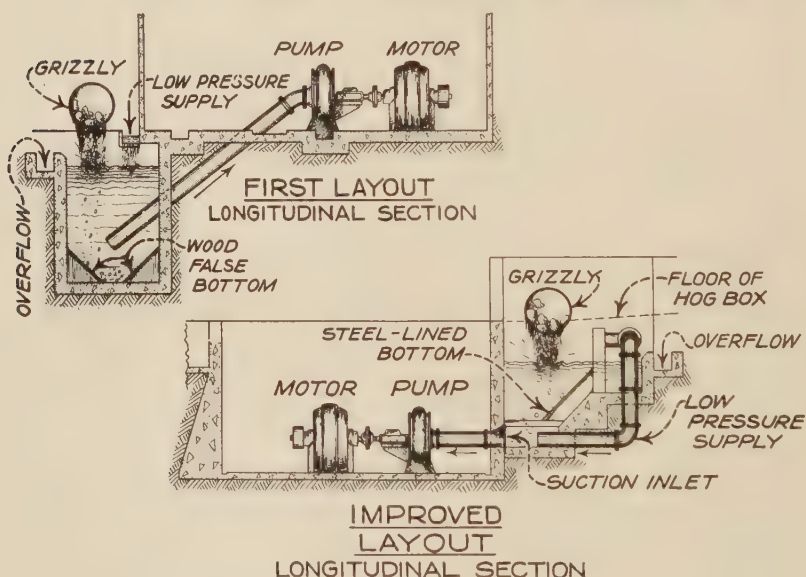


FIG. 95.—Improved sump for dredge pumps.

The upper view shows the original installation, and the lower one the improved layout which gave much better results.

giants at the hog box) was brought into the bottom of the sump directly opposite and on line with the suction line, and the revolving screen overhead was set in such position that all material dropped into the sump directly over the gap across which this low-pressure water supply was being fed to the pump. Figure 95 illustrates the improved sump design and also shows comparison with the original layout. The new design eliminated suction troubles almost entirely, it cut down to a minimum the loss of head in the suction line, and it eliminated priming troubles

entirely, as the dredge pump was under pressure whenever there was water in the sump.

Dredge Pumps.—Fifteen-inch pumps were selected as standard for all the hydraulic-fill operations. The determination upon this size was influenced by two things: first, that a 15-in. pump which was fed to capacity would build up the embankment about as fast as it seems safe that a hydraulic fill should be brought up, giving reasonable time for compacting; and second, that a larger pump would have materially increased the difficulties of water supply and disposal. All these pumps were electrically operated, the motors varying in size from 250 to 500 hp., depending on local conditions.

The first pumps installed had cast-iron shells and runners. It was found that, with this heavy material which was being handled at the dams, these cast-iron runners were good for only about 10,000 to 12,000 cu. yd. The replacement of runners became at once a source of serious expense and delay. The shells themselves were good for about 100,000 cu. yd., when they had to be either discarded or repaired. The first step towards improvement of pumping equipment was the substitution of manganese steel runners, and at the same time a design was perfected for removable manganese shoes for the runners, so that instead of discarding the whole runner when the tips of the vanes had been worn off, it was only necessary to put on a new set of shoes. In this way the life of the runners was increased to between 100,000 and 200,000 cu. yd.

The next step was the introduction of manganese-steel shells, which gave more than double the length of service that the cast-iron shells were good for, and later a full manganese-steel pump of simple design was adopted as standard at all the dams. This was a simple pump without liner plates. Figure 96 shows the general design of the runner, which was worked out by the district's engineers in cooperation with the manufacturers, with the idea of getting a runner that would be most satisfactory from the standpoint of efficiency, durability, and freedom from clogging. It was the practice to substitute these new pumps for the original ones at each of the dams, after all possible life had been obtained from the original installations.

Manganese steel was expensive, and because of shrinkage stresses in the material during the process of casting, it was impractical to make these shells more than $2\frac{1}{2}$ to $2\frac{3}{4}$ in. in thick-

ness. This meant throwing away a lot of expensive metal when the shell was worn thin in one place. The suggestion was made that the metal commonly known as white iron might be suitable for these shells. This so-called white iron is very hard, and when properly doctored up to give it the requisite toughness, and properly handled in casting, it was thought that it might give satisfactory service. It had this advantage, that it could be cast in any thickness desired without trouble from shrinkage stresses;

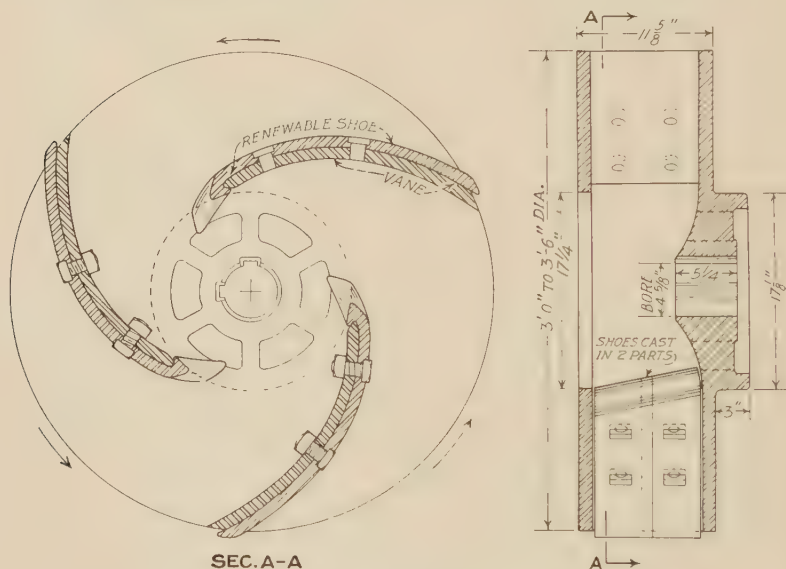


FIG. 96.—Standard impeller for dredge pump.

These impellers were of manganese steel with removable manganese-steel shoes on the vanes. The effective size of the impeller could be increased by replacing shoes with longer ones. However, it was found best not to allow a shoe to project more than 2 in. before changing to the larger-size impeller.

also it could be obtained locally at a cost considerably below that of manganese steel.

Some study was given to this matter, and finally two white-iron shells were made. They were given a thickness of about $5\frac{1}{2}$ in. at the bottom where the most wear occurs, and the thickness was gradually reduced to about $3\frac{1}{2}$ to 4 in. at the top. Transverse ribs were cast around the shell to prevent it from splitting when it had become worn thin. The first of these castings was very hard, and the finishing work on the few surfaces that required it was done with great difficulty. This shell gave very

satisfactory service compared with the others that had been in use up to that time. It finished its first job, and a second one, handling about 560,000 cu. yd. of material, and still had a $2\frac{1}{2}$ -in. thickness of metal left in the bottom. The second of these shells was made somewhat softer than the first. It finished the job where it was first installed and was judged to be not more than half worn out after an output of 430,000 cu. yd. Three other white-iron shells were cast later, slightly different compositions being used in each of them, but unfortunately, in the effort to reduce the cost of finishing, toughness and durability were sacrificed, and although one of the later shells gave fairly good service, none of them were as good as either of the first two. It was found also that the metal in these shells, particularly the later ones, was not homogeneous. Two of them wore entirely through at soft spots while only ordinary wear occurred elsewhere. By the time this much experience had been gained from these shells, the work was getting to the point where there was pumping equipment enough on the job to finish it, so that the experiments were not carried on to conclusion. But there is no doubt that some special metal, based on the white-iron formula, is well suited to the manufacture of these dredge-pump shells, and will give service comparable with manganese steel almost pound for pound, with the added advantage that the thickness of the castings may be increased at the points where the greatest wear occurs, thereby wasting less metal when the shell is finally worn out, and getting longer life from the shells at a considerable saving in cost.

Incidentally, white-iron castings were tried for runners for some of the original dredge-pump equipment, but were not satisfactory. As the manganese runners as later used, with removable shoes, were giving good service by that time, no further investigation of white-iron runners was made.

Dredge Pipe.—The first section of discharge pipe beyond the dredge pump was usually a more or less permanent installation, and for that section standard 15-in. wrought-iron flanged pipe was used, having a thickness of $\frac{3}{8}$ to $\frac{1}{2}$ in. The standard pipe for the rest of the discharge line where frequent moving was necessary, was riveted or welded pipe of No. 8 to No. 10 gage steel plate, built up in 16-ft. lengths, with stove-pipe joints. When the installation was first planned, it was expected to use the standard riveted dredge pipe of mild steel. It had an average life of about 100,000 cu. yd. for material such as was handled

at most of the dams. A high-carbon, electrically welded steel pipe was worked out, which was manufactured at a cost practically the same as that of the standard riveted pipe, and gave service about three times as long. On two of the first installations this high-carbon pipe was laid in the discharge lines along with the riveted pipe in alternate lengths, so that the two were subjected to exactly the same service conditions. It very soon became evident that the high-carbon pipe was far superior, and it was used exclusively after the first order of mild-steel pipe had been worn out. At Germantown, where the material pumped had a preponderance of gravel, the average life of the mild-steel pipe was a little under 100,000 cu. yd., while that of the high-carbon pipe was about 315,000 cu. yd. At Taylorsville, the mild-steel pipe had a life of about 150,000 cu. yd., while the high-carbon pipe averaged about 500,000 cu. yd.

At the joints, the pipe was held together by loops of wire wound around projecting lugs, near the end of each length. To insure an even wear around the circumference it was the practice to turn each length of pipe one-third the way around for each run. This was easily kept track of by making three marks around the circumference 120 deg. apart, numbered 1, 2, and 3. Obviously the lower third of the circumference of a dredge-pipe line gets practically all the wear, and this method distributed the wear uniformly in the pipe.

Friction heads in the dredge pipe varied from 4 to 14 ft. per 100 at the different dams, depending upon the kind of material being pumped. The lowest records were at Taylorsville, as would be expected, where the material being handled was glacial till and clay. At Lockington the average friction loss was about 6 ft. per 100, which is lower than at any of the other dams where heavy gravel was being pumped. There was blue clay in the borrow pit at Lockington which was drawn upon as needed to give a proper mixture of materials for the dam. Apparently the lubricating effect of this blue clay, in the amounts required to give sufficient fines for the hydraulic core, had a marked effect in reducing the friction loss in the discharge pipe. It may be also that the sluicing of all materials to the sumps at Taylorsville and Lockington had something to do with the lower friction losses, because of the thorough working over of the material by the giants and in the ground sluices. At Germantown and Huffman the friction heads averaged around 7 to 10 ft. per 100, and

at Englewood at times they ran as high as 10 to 14 ft. The maximum velocity maintained in the dredge pipe was approximately 12 ft. per second, except that at Englewood, where the highest friction losses occurred, the velocities in the dredge pipe were sometimes increased to 14 or 15 ft. per second.

These high friction heads had the effect of limiting the lengths of discharge lines and requiring the use of booster pumps at an earlier stage of the work than had been expected. For example, one of these dredge pumps, good for service against a head of 135 ft., would be limited to a discharge line 1,000 ft. long, if it were pumping against a static head of 20 ft. and the friction loss in the pipe ran up to 12 ft. per 100. There was no economy in trying to work the pumps at a disadvantage under such conditions.

Partly because of the high friction losses, and partly to reduce wear in the pipe, it was the general practice to line up the discharge pipes carefully each time they were run out. It was not usually feasible to do this for each length as it was added on, but the line was straightened up as soon as possible after it was put into operation. There is no doubt that this is an economical procedure, both in saving power, and in prolonging the life of the pipe. It also was conducive to smoother operation of the pumping plant, in that clogging of the pipe was less likely to occur than if there were sags in the line where the heavy material would tend to collect and start to form a plug.

Pumping Practice.—The first requisite for satisfactory operation of the pumping plant was a reasonably steady flow of materials to the pump. This was accomplished by careful training of the nozzle man in the hog box. With a little practice he could maintain a steady flow, at the same time working boulders and objectionable lumps of clay off to one side, and preventing the material in the pile from sliding off in masses. It was the general practice for the nozzle man to feed the material to the sump as fast as he could unless he got a signal from the pump man to slow down. An electric signal service was installed between pump man and nozzle man for this purpose.

Given a fairly steady flow to the sump, the next thing is to maintain a steady discharge, by avoiding clogging or plugging in the suction, in the pump, or in the discharge line. It was found that the fluctuation of water level in the sump, together with the readings of vacuum gage, pressure gage, and ammeter, was the

most prompt and reliable indication of impending trouble. After the pump speeds and water supply have once been adjusted to the economical discharge from the hog box, any rise or fall of water surface in the sump may be taken as a danger signal. The gage and ammeter readings help to locate the trouble. For example, if the water in the sump rises, and the reading of the pressure gage increases at the same time that the ammeter reading decreases, it means that the discharge line is being overloaded. On the other hand, if the water level in the sump lowers, and the reading of the pressure gage lowers, while the ammeter indicates increased power consumption, then the pump is not handling as much material as it might. If the water in the sump rises, and the reading of the vacuum gage increases, with the pressure gage showing decreased pressure, trouble is starting in the suction line. A trained operator can read these signs very quickly and accurately, and therefore, for most efficient service, it was necessary to have all of these indicators within plain sight of the operator. In some cases it was not possible for the operator to see the water level in the sump, and in such cases it was necessary to arrange an electrical device which would register, on the operator's switchboard, fluctuations of water surface in the sump.

Obviously, all the dredge-pump motors had to be of the variable-speed type. The best plan was to hold these motors, for normal operation, two or three notches below the point of maximum power. Then, when there was indication of an overload in the discharge line, a gradual increase in speed was usually sufficient to clear it out. If the trouble did not clear up immediately, another increase of speed, together with a signal to the nozzle man to slow up the feed from the hog box, was usually sufficient. If indications showed that there was trouble in the suction line, the feed from the hog box would be shut off immediately and the trouble could usually be overcome by alternately slowing down and speeding up the pump.

During the first year or two of dredge pump operation, plugs in suction and discharge lines were not uncommon. Even the pumps themselves were sometimes choked up with a nest of large stones, or by a bar, or stick of timber, or something of the sort that would occasionally get into the sump in some unknown manner. As the pump operators became more skilful, however, and the significance of sump levels, together with gage and ammeter

readings, became better understood, trouble from plugs became more and more infrequent, until towards the end of the job they were almost entirely eliminated. At the same time average daily outputs were constantly being increased.

Now it is evident that the easiest way to avoid plugs in the pumping system is continually to pump a lean mixture. A pump runner can always play safe by constantly keeping down his percentage of solids. One of the problems of this job was to encourage the pump man to keep his discharge line loaded almost to the point of plugging, without actually reaching that state. The cost of pumping operations was practically the same, per day, whether the percentage of solids was low or high. If a lean mixture was being run, the actual quantity of embankment material handled during a given period might be less than half what could be obtained without perceptibly increasing the daily cost of operation. Graphic ammeter charts, and records of cars dumped, were posted in conspicuous places and promoted the friendly rivalry necessary to produce best results. As a matter of fact, as will be explained later, the pumps were not crowded up to maximum possible output by the excavating equipment at any of the dams, so it was only necessary to maintain a reasonably steady gait at the pumps, in order to keep up with the delivery of material to the hog boxes. There was always the chance, however, to keep the power consumption down to a minimum for the amount of material handled, so the ammeter and car records, taken together, gave a basis for judging the efficiency of pump operators.

It has been mentioned that the manganese-steel pump runners were equipped with removable shoes. The original idea was entirely one of economy, making it possible to replace worn parts instead of scrapping a whole runner. These removable shoes served another useful purpose, in improving the efficiency of the pumps as the static heads or lengths of discharge lines increased. By having shoes on hand of different lengths, it was possible to increase the effective diameter of the runner by simply putting on a set of longer shoes (see Fig. 96). It was the practice to have runners of two sizes, *i.e.*, 36- and 42-in. For the 36-in. runner, 36-, 38-, and 40-in. shoes were kept in stock. The 42-in. runners could be equipped with either 42-, 44-, or 46-in. shoes, so that a dredge pump requiring to be operated under heads varying from say 25 to 150 ft. could easily be equipped with any size

runner required. This made it possible to continue in economical use, a runner which otherwise would have to be thrown away, or continued in operation at low efficiency. It was quickly found that there is no economy in trying to continue in operation, a runner which is worn down so as to lose its efficiency. The ability to replace shoes quickly, helped to minimize uneconomical operation under these conditions, but it was the practice to go even further, and to discard a runner promptly when it had become worn to the extent that the replacement of shoes would no longer restore its efficiency.

There is a question whether the maximum capacity of these 15-in. dredge pumps was ever determined during the progress of this work. More than 7,000,000 cu. yd. of material were pumped into the five dams. At none of the dams was the excavating equipment of sufficient capacity to keep the dredge pumps loaded up to their maximum capacity. To show the possibilities of this type of equipment, even with the heavy material that was handled at most of the dams, and to show the gradual increase in output that was attained, the following records are set down; the highest of these, perhaps, approach the maximum capacities of the pumps under these conditions: A run of between 300 and 400 yd. per hour for several consecutive hours, or even for full shifts, was not uncommon. At one of the dams 91,500 cu. yd. were put through a single pump in one month of 25 working days, two 10-hr. shifts per day. At another dam two dredge pumps handled 180,000 cu. yd. in one month, and it is known that the second pump was in operation only a part of the time.

One pump handled 2,100 cu. yd. in $8\frac{1}{2}$ hr. of pumping, or an average of 247 cu. yd. per hour.

Another handled 2,583 cu. yd. in 9 hr., an average of 287 cu. yd. per hour; the same pump at another time put out 2,808 cu. yd. in $9\frac{1}{2}$ hr., or an average of 295 cu. yd. per hour, for practically a full shift.

There is another record of 2,916 cu. yd. in $8\frac{1}{2}$ hr., an average of 343 cu. yd. per hour; another of 4,000 cu. yd. in 9 hr., or 444 cu. yd. per hour; another of 4,050 cu. yd. in $8\frac{3}{4}$ hr., or 463 cu. yd. per hour, and another of 4,590 cu. yd. in 8.8 hr., or 522 cu. yd. per hour.

The highest recorded rates of pumping were 2,800 cu. yd. in 4.83 hr., or an average of 575 cu. yd. per hour, and 2,781 cu. yd. in 4.41 hr., or 630 cu. yd. per hour.

These quantities are given as in the embankment of the dam, car measurements being corrected to an average of $8\frac{1}{2}$ cu. yd. per car, which is the result of long-time records of carloads as equated against actual measurements.

Booster Pumps.—Booster pumps were provided for when the original installations were planned, and their use was similar at the various dams, although their locations in the line were varied. At Lockington the booster pump was set in the main pump house and could be connected up direct with either of the two primary pumps. At the other places the booster was set some distance out on the discharge line. At Germantown and Taylorsville this distance approximated the reach of the primary pump, while at Huffman the booster was only a short distance up the slope above the main pump house. There was some discussion as to whether the location of the booster, along the discharge line, made any difference in the efficiency of the system. Theoretically, if the material being pumped were a perfect fluid, there would be no difference, but it is very evident that the material handled by dredge pumps, particularly that under consideration here, is not by any means a perfect fluid, and there was a strong opinion among some of the men interested, that there was some definite location on the discharge line where the booster should be installed to give most economical service. No definite information on this point was obtainable. The installations worked satisfactorily at all of the dams, and so many varying conditions were present affecting the efficiency and output of the pumping units, that it was not possible to arrive at a solution of this question.

The boosters were exact duplicates of the primary pumps, and the essential details of their operation were similar. As the discharge line of the primary pump connected into the suction of the booster, the latter was operated normally under some pressure. This varied from a maximum at Lockington, to a minimum at Germantown or Taylorsville, but was an appreciable amount even at the latter places. For best results both pumps should be run at the same speed, and therefore it was necessary for the two operators to be in close communication in order that one might respond promptly to a necessary change of speed on the part of the other. This was accomplished by a simple electrical connection which indicated on the switchboard

at each pump how far open the other one was running. This answered the purpose admirably.

Elevated Sumps at Englewood.—The use of a booster pump on the line practically doubles the power cost for each cubic yard of material handled. On account of the height and length of the embankment at Englewood, two or more booster pumps would be required on the line for the upper part of the dam, representing a large yardage, if all the material were to be handled through the original hog box. After some study of this problem, it was concluded that it would be cheaper, at Englewood, to eliminate the necessity for some of the booster pumps, by building additional hog boxes higher up on the slope of the dam, and properly spaced along the slope. This meant, of course, additional cost of hauling up the grades to these higher elevations, but it was estimated that the saving in power costs for pumping, would more than make up for the additional cost of hauling in the trains.

Accordingly, three additional sumps were built at Englewood along the upstream slope of the dam, and about equally spaced across the valley. They were so located that the whole dam could be completed without the use of booster pumps at all. Complete pumping equipment was installed at each of these sumps, but in order to avoid the necessity of purchasing additional 500-hp. motors, it was decided to move the motors back and forth between the two end sumps while the pumping for that lift was being carried on from the middle one. In other words, the practice was to start a lift at one end of the dam, and as soon as the work had passed beyond the range of the sump at that end, move the motors over to the sump at the other end, and have them ready to pick up the work as soon as it got beyond the territory covered by the middle sump. Then the next lift would be doubled back on the preceding one and the process reversed.

These elevated sumps were not built all at once, as the construction program did not make that necessary. Therefore, an opportunity was given to put into effect some improvements in sump design which had been suggested by the operations up to that time, and to give further study and observation with the possibility of incorporating other improvements in the later installations. The final results have been shown in the discussion of sumps in a previous part of this chapter. At Engle-

wood it was even possible to discharge the oversize rock from the revolving screen direct into standard gage cars, without intermediate handling.

Whether or not the elevated sumps at Englewood justified their use in place of booster pumps (and there is no feeling that they did not), it is certain that they resulted in economy on the hydraulic-fill operations as a whole, because of the opportunity they gave of carrying forward the studies towards improved sump and hog box design. They also permitted the work to go on to completion at Englewood without adding another unit to the plant layout, which always means another possible source of trouble.

Preparation of Foundations.—Before the hydraulic fill was started, the foundation for the embankment was prepared by stripping off the top soil, to a depth of a foot or more, in order to remove objectionable vegetable matter, and large roots were dug out. A cutoff trench was dug along the center line of the dam varying in depth from 5 to 15 or 20 ft. This trench was dug by a dragline machine, and the material excavated from it was thrown over into the downstream portion of the dam, clear of the core section. The cutoff trench was to be filled with core material. It was desirable also that there be a layer of impervious material connected with the impervious core, and extending upstream to form a blanket over the porous substrata. At most of the dams, except in the river channel itself, this impervious layer was found to be present, but not always in sufficient thickness. Careful examination was made by means of post-hole diggers, over the whole area up stream from the cutoff trench, to beyond the upstream toe at each dam, and where an impervious overburden was not present to a depth of 3 or 4 ft. the thin places were reinforced with artificial patches of selected material put down in layers and rolled. Thus, a complete impervious blanket was formed over the upstream portion of the foundation. In the river channel sections, an artificial blanket over the whole area was usually required, and in some cases this upstream blanket was extended beyond the limits of the upstream toe of the dam, by diverting and properly confining on those areas the waste from the hydraulic core pool. It was endeavored to keep the shortest line of seepage travel under the dam of such length that its ratio to static head, at any point, would be not less than about 7 to 1.

Handling Materials in the Fill.—The plans provided that the width of the impervious core of a dam at any point should be approximately the same as the height of the dam above that point. Extreme care was taken at the beginning of the embankment construction not to allow the core material to spread out beyond its theoretical limits, as that is a condition that has caused trouble at some hydraulic fill dams in the past. To start the hydraulic fill, dikes were thrown up along the upstream and downstream toes, the dredge pipe was laid parallel and close to the line of the outer slope, and as the fill was being shaped up, the pool and the core material were quickly crowded into the area prescribed for them in the original design. This was some-

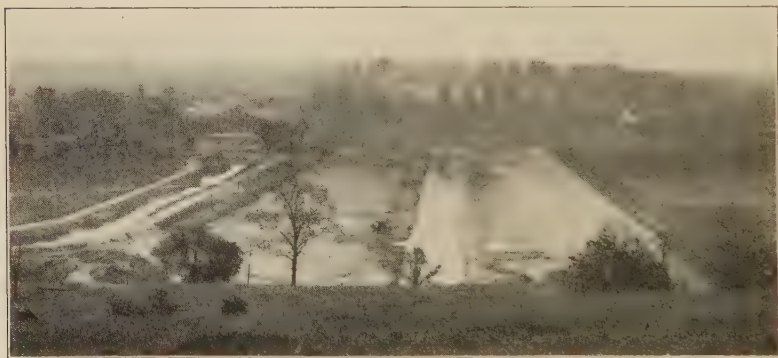


FIG. 97.—Foundation shaped up ready for hydraulic fill.

times accomplished by throwing the discharge line over towards the middle section of the dam; sometimes a dragline machine was used to shape up the work at the start; teams were used in some cases; the object being to bring the work into shape as soon as possible at the very beginning, so that the regular hydraulic fill procedure could be instituted at once. Figure 97 shows one of the jobs shaped up ready for the beginning of the regular hydraulic fill.

Low levees were thrown up along the outer edges of the slope, and kept ahead of the hydraulic fill, to turn the flow from the dredge pipe in towards the central core pool. These small levees were simple affairs, sometimes thrown up by dragline machines kept on the dams, sometimes by teams, and sometimes by hand. One of the most useful pieces of equipment for this purpose, was the small back-filling machine illustrated

in Fig. 98. The dredge pipe was laid just inside these levees and parallel to them as shown in Fig. 99. The natural deposition of the material forms a gently sloping beach from the line of the dredge pipe to the edge of the core pool, and the width of core is controlled by raising or lowering the water level in the pool. The natural result of the hydraulic-fill process is to deposit the coarsest of the material under the discharge end of the pipe and



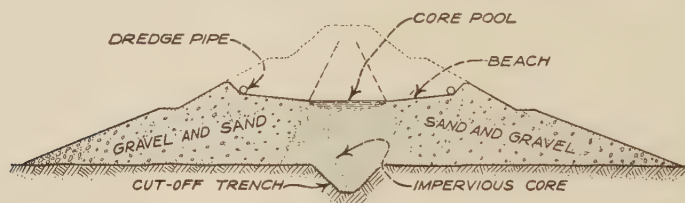
FIG. 98.—Backfilling machine throwing up slope levees for hydraulic fill.

This little machine was found very convenient for this purpose. Similar work was done at other dams by dragline machine and by teams. This backfilling machine, however, gave most economical results.

therefore near the outer slope of the dam. The rest of the materials are carried down the beach with the water, the coarser of them dropping along the way until, when the edge of the core pool is reached, the retarding of the flow there causes all but the very finest of the clay and silt to be deposited along the edge of the pool. Within the pool this clay and silt gradually settles down through the water, forming the impervious core of the dam. The beach assumes a natural slope, which is more or less

steep according as the material in the fill is coarser or finer. The slopes of the beaches, with materials used in the construction of these dams, varied from about 10 to 1 for the coarsest gravel, to about 15 to 1 for the more clayey material, like that at Taylorsville.

The fill was usually brought up in lifts varying in thickness from 2 to 4 ft., the thinner lifts where the beach slopes were less steep, so that the raising of the water surface of the pool to the required height would not run it too far back on the beach, and thus tend to give too wide a core. These lifts were started at one end of a section of embankment, and carried through continuously to the other end by adding on one length of dredge pipe



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FIG. 99.—The hydraulic-fill process.

Discharge lines from the dredge pumps are laid parallel to the outer slope just inside the slope levee. A natural deposition of material forms a gently sloping beach from the outer slope to the core pool, leaving the coarser material near the outside slopes and carrying the fines to the core section. The width of core is controlled by raising or lowering the water level in the pool. At the edge of the pool the retarding of flow down the beach causes all except the very finest of the material to be deposited, leaving the finest of the clay and silt to gradually settle down through the water, forming the impervious core of the dam.

at a time, filling up the layer to the required height as the work proceeded. Care was taken to maintain the shore line of the pool fairly straight, so as to keep the width of core reasonably uniform (see Fig. 100). In case the flow down the beach from the dredge pipe was allowed to concentrate, there was liability that it might carry too much material with it, or actually attain a scouring velocity and take some of the coarse material from the beach out into, and part way across, the core section. These tongues of coarse material shooting out into the core are an ever-present menace in hydraulic-fill dam construction, the danger being that some of them from opposite sides may meet and form porous channels through the core section. Various devices were made use of to obviate this danger. Baffle boards on the slope

to spread out the flow down the beach, and baffle floats or booms formed by timbers floating on the pool and moored in close to the shore, were both effective in curing the trouble. A most essential requisite, in this connection, was to keep the core well filled up with solids, by so selecting the materials in the borrow pits that an abundance of core material would be available, and the progress of fill on the beaches would not get far ahead of that in the core itself. Otherwise it was almost impossible to keep the beach material from encroaching on the core.



FIG. 100.—Hydraulic fill under construction.

Showing the end of the discharge line from the dredge pumps and the lift of hydraulic fill being brought forward.

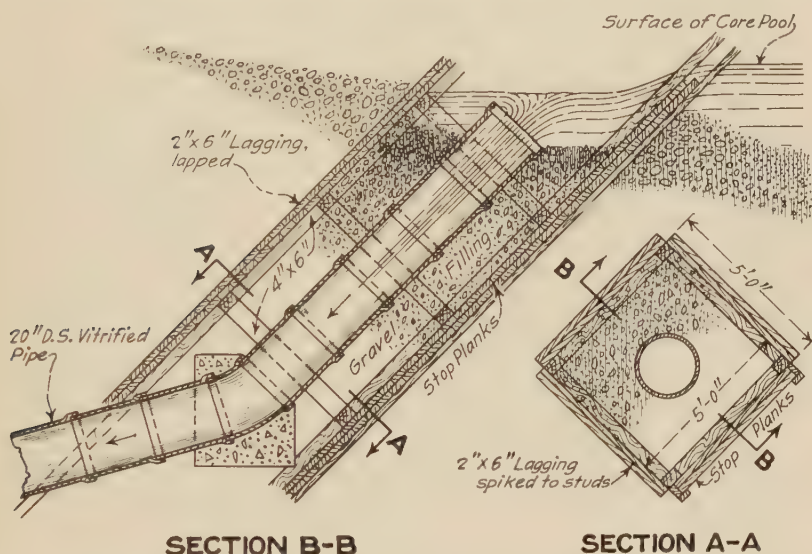
Deposition of Materials.—The theoretical distribution of materials in a hydraulic-fill dam, is for the coarsest of the material to be deposited in the outer slopes, with a gradual change to smaller and smaller sizes as the edge of the core pool is approached. In the Conservancy dams, while this gradation was discernible in a general way, it was only after close inspection that any difference in character of the material outside the core section, would be noticed. The material near the outside slope did contain a larger percentage of cobbles and coarse gravel, but there was coarse material to be found all through the fill right up to the edge of the core. On the other hand, a close examination would show a preponderance of fine gravel and sand near the edge of the core zone, but sand and fine gravel are also to be found in abundance near the outer slopes; so the gradation, as one follows down the slope of the beach, is not as apparent as might be supposed.

That, in itself, is of little consequence so long as the outer slope material is more porous and free draining than that farther in towards the core, as it undoubtedly is. There is always enough gradation for that. But there is another consideration that should not be overlooked. Just as the fine gravel and sand is trapped in the outside slope material, when theoretically it should be deposited farther down the beach, so a considerable quantity of fine core material is held back in the same way and never reaches the core section at all. This has no effect on the outside slope material, and is in no way objectionable except in cases where there is a scarcity of core material to begin with. Then it simply increases the shortage. In an analysis of borrow-pit materials this should be kept in mind. An apparent surplus of core materials should be present in order to take care of this loss in the fill.

Wasteways.—Some way had to be provided to dispose of the surplus water from the core pool. Except for what was taken care of by evaporation and seepage, all the water that was pumped up into the pool had to be disposed of as soon as it had dropped its load. At the three dams where the combination outlet and spillway structure was used, a semi-circular vertical groove about 4 ft. in diameter was built down the back of the retaining wall, leading to a temporary opening through the wall at the bottom, into the outlet channel. This groove was formed into a well as the fill was brought up, by laying up semi-circular ribs of pre-cast concrete about 6 in. thick, one at a time, to keep pace with the fill and provide a spillway at suitable height for the overflow from the core pool. This provided adequate and safe control at slight expense. When the fill was completed, the outlet from this well was closed with concrete. A manhole cover was placed over the top so that the well might be used in the future for inspection purposes, tapered wooden plugs, which could be removed from the inside, having been provided through some of the rib sections, giving access to the core at various elevations.

At the other two dams pipe outlets had to be provided, and these were extended up as the work on the fill proceeded. It had already been determined by experience elsewhere, that it was practically impossible to maintain these pipe outlets within the core section, because of the fact that there is more or less movement and shifting within the core itself while the filling

is going on, and until the process of consolidation is well along. It was necessary, therefore, to bring up these pipe outlets within the more stable outer sections of the fill, with a temporary structure at the edge of the core pool to regulate the height of water and the outflow. Figure 101 shows how this was accomplished at Englewood, and this may be considered a typical installation for the purpose. A line of 20-in. double-strength vitrified pipe was laid up into the slope from a convenient outlet point, to a point within a few feet of the theoretical edge of the core. There



SECTION B-B

SECTION A-A

FIG. 101.—Wasteway for core pool.

Showing one method of handling the overflow from the core pool.

the slope was changed so as to keep just outside the core limits, and a wooden box was built around the pipe forming a casing or well on the same vertical slope as the pipe itself. The side of this timber casing facing the core pool was built up of stop planks, which were inserted as the water level in the pool was raised, giving the necessary overflow control. The other three sides were kept above water level. Pipes were added on as the fill was built up, and the space around the pipe within the timber casing was filled with tamped gravel. The pipes were laid carefully, with mortar joints, and the bend at the bottom of the steep slope was backed up with concrete so as to prevent settlement or push-

ing out of place. This was an important feature of the hydraulic-fill arrangement and required care in construction to insure continuous service. When the fill was completed, the upper part of the timber casing was removed, and the pipe filled with fine gravel and left in place in the embankment.

At most of the dams additional wasteways were built at the ends by paving the gutters up the slopes where the fills joined the hillsides, and connecting into the core pools by a length or two of dredge pipe through temporary earth dams, which were removed and rebuilt at higher elevations as the fill was built up.

At Englewood, when the elevated sumps were in use, the wasteways discharged back into the sumps, in order to save the extra pumping lift for the low pressure water. This had the disadvantage of working over and over the very finest of the core material which was carried back with the waste water, and caused some trouble at times, but on the whole it resulted in economy of operation.

Controlling Width of Core. Several incidental references have already been made to the matter of controlling core widths. First of all, there must be a sufficient proportion of fines in the borrow-pit material to give the necessary amount for the theoretical core section, with enough surplus to take care of the amount held back with the coarser materials along the beaches, and enough additional surplus to permit some leeway in the manipulation of the overflow from the core pool. An excess of 20 per cent over the amount indicated by the theoretical core section is not too much. Without this "working surplus" of core material, encroachment of the coarse material into the core area is inevitable. The core material of the Conservancy dams was practically all fine enough to pass a 100-mesh and about 80 per cent of it would pass the 200-mesh sieve.

Given the proper percentage of fines in the borrow-pit material, the usual method of controlling core width is by raising or lowering the water level in the core pool. Along the edges of the pool, where the flow down the beach is checked by entering the still water, all particles coarser than the very finest of the sands are deposited, and the limits of the core are fixed. The use of shear-boards and floating baffles, to break up concentration of flow down the beaches, has already been mentioned. If tongues of gravel or sand persist in shooting out into the core, the use of lower lifts in building up the fill will be found advisable. The

shore line of the pool should be kept even and regular in order that the core area shall be well defined. A surplus of fines may be wasted, by lowering the spillway at the wasteway. For most satisfactory operation this surplus of fines in the pool itself is almost necessary, furnishing a reserve which can be drawn upon to a greater or less extent as needed, in the regulation of core widths.

This careful regulation of core widths is a most important feature of hydraulic-fill dam construction. Once it gets out of con-



FIG. 102.—Hydraulic fill near completion.

This shows the top of the Englewood dam. The core section is definitely outlined here, and as the water has been lowered slightly, the appearance of the core material may be noted in the foreground. This is near the top of the dam, and as the core becomes narrower, it is increasingly difficult to maintain it as a definite section. Special methods were used for topping off the dams.

trol the whole structure of the dam is endangered, either by the formation of porous channels through the dam, or by the sloughing of the outside slope material into the core, thus affecting the stability of the structure.

Core Studies and Tests.—Careful study was given to the design of the core for the Conservancy dams, with the result that the core width at any point was made equal to the height of the dam above that point. This gave a core of such shape that sloughing in of the outside slope material would not be encouraged, of sufficient width so that with reasonable care the encroaching of sand

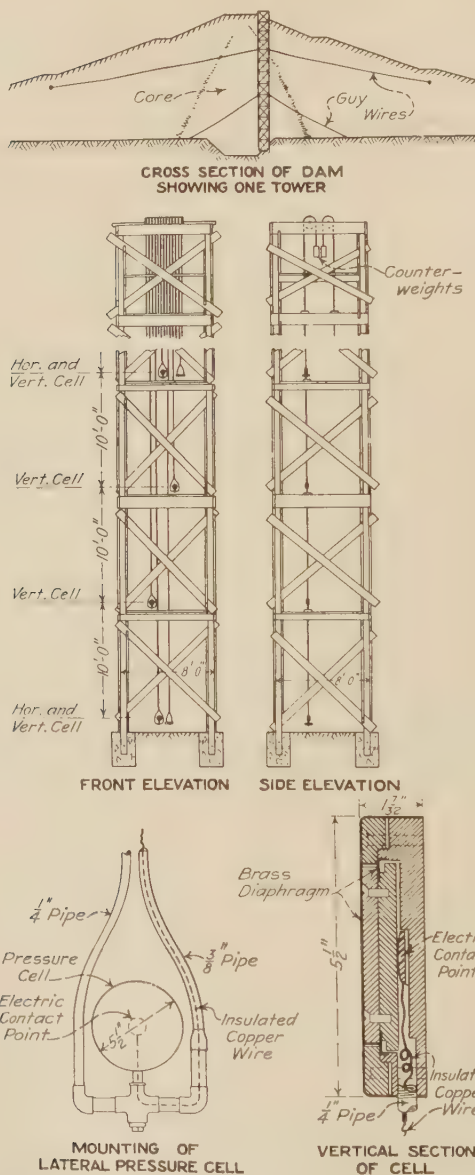


FIG. 103.—The Goldbeck pressure cell and first method of installation.

The pressure cell is shown in cross-section in the lower right-hand view, and its method of operation will be understood by reference to the text. This method of installation was not satisfactory and was improved later as shown in Fig. 106.

and gravel too far into the core zone could be prevented, and narrow enough so that additional material to that required to give stable slopes would not be necessary to hold the pressure of the semi-liquid part of the core during construction (see Fig. 91).

In order to obtain cores of the dimensions decided on, it became necessary at one of the dams (Taylorsville) to waste a considerable quantity of the core material available in the borrow pit, and at two others (Germantown and Huffman) to open auxiliary pits in clay deposits on adjacent hillsides, to make up for deficiency of fines in the main borrow pits. There are decided advantages in having a surplus of core material available, so that a part at least of the finest of that material may be wasted: First, a better gradation of core material may thus be obtained; in fact, after the selection of the borrow pits, and such selection of material in the pit as is practicable as excavation proceeds, the wasting of fines affords about the only remaining opportunity to control the gradation of the core material; and second, a more rapid consolidation of core results by getting rid of some of the extremely fine particles which, otherwise, are held in suspension for a long period, tend to lubricate the whole mass, and retard the process of consolidation by holding up particles which of themselves would settle more rapidly.

In order to study the action of the hydraulic-fill cores during construction, it was determined to place at various elevations, in all the dams, a number of Goldbeck pressure cells. Preliminary experiments with these cells at the U. S. Bureau of Public Roads indicated that they would give reasonably correct results if placed in hydraulic-fill cores. Briefly, the Goldbeck cell (Fig. 103) is a closed, flat, circular box, $5\frac{1}{2}$ in. in diameter, similar in shape to a shoe-blackening box, the top or bottom of which acts as a movable diaphragm. It is operated by slowly admitting compressed air, through a small pipe, to the inside of the box. The air is supplied from a small tank which may be charged with an ordinary tire pump. The cell is buried at a known elevation in the core, and the movable diaphragm is held down by the pressure of the material. When the pressure of the air on the inside equals the pressure of the material on the outside, the diaphragm is lifted slightly, an electric contact is broken, and an indicator light in the registering apparatus goes out. At that instant, the gage on the air line indicates the pressure of the material against the movable diaphragm. The operation of the

cell requires a movement of the diaphragm of less than 0.0001 in. The cell may be set either horizontally or vertically, and thus either vertical or lateral pressure may be determined.

The limitation of fines in the core material was largely a matter of judgment, based on the analyses of core materials available, preliminary tests made in cooperation with the U. S. Bureau of Public Roads, and analyses of core samples secured from other hydraulic-fill dams. After construction was started, frequent analyses of the core materials were obtained through the U. S. Bureau of Soils, and the rates of consolidation were studied. Table XIX shows the results of some of the analyses of typical core material. Although cores of quite different compositions from those given may show as good results, it may be said that all five of these dams were completed without the least indication of trouble with any of the cores, with ample proof that consolidation has taken place in a thoroughly satisfactory manner, and that the water-tightness of the core, as shown by several tests, is all that could be desired. In other words, while it is not claimed that the gradation shown by these analyses cannot be improved, still these results indicate that cores of about the composition shown are eminently satisfactory from the standpoints of rate of consolidation, degree of consolidation, and water-tightness.

About fifty of the Goldbeck pressure cells were placed in the cores of these five dams. Some have given satisfactory readings, and some have not. In cases where the readings seem unreasonable, or where the cells fail to register, it is sometimes difficult to determine whether the trouble is in the cell or is due to faulty installation. With a few exceptions, there is no evidence that any of the unsatisfactory results have been due to any fault in the cell itself. Defective installation is known to have been the cause of many of the unsatisfactory readings, and improvements in installation have resulted in marked improvements in results. This was a pioneer effort and, naturally, much was to be learned by experience before proper methods were determined for meeting the requirements, particularly as to the best methods of installation. The first installation was made at the Germantown dam, as shown in Fig. 103. At this dam, the cells were suspended by two $\frac{1}{4}$ -in. pipes from the top of a framed tower which was built in sections as the construction proceeded. Two pipes were necessary at these installations, one to carry the wire connecting

TABLE XIX.—MECHANICAL ANALYSES OF TYPICAL CORE SAMPLES

Bureau of soils, standard sizing	Germantown	Englewood	Lockington	Taylorsville	Huffman	Average
Percentage of fine gravel, 2 to 1 mm.	0	0	0	0	0	0
Percentage of coarse sand, 1 to 0.05 mm.	0	0	0	0	0	0
Percentage of me- dium sand, 0.5 to 0.25 mm.	0.1	0	0	0	0	0.1
Percentage of fine sand, 0.25 to 0.10 mm.	1.5	4.2	2.1	4.6	1.6	3.6
Percentage of very fine sand, 0.10 to 0.05 mm.	14.0	17.3	21.2	19.6	16.8	19.3
Percentage of silt, 0.05 to 0.005 mm.	64.2	56.0	55.2	52.7	57.7	55.2
Percentage of clay, 0.005 to 0 mm.	20.3	22.5	21.5	22.6	23.9	22.0

with the registering apparatus and to take the charge of compressed air, and the other to be used as a blow-off in case water entered the pipe or the cell. This method of installation, however, was improved later (Fig. 106).

Cells were set in a vertical position (to measure lateral pressures) at 10-ft. vertical intervals, and in horizontal position (to measure vertical pressures) at 30-ft. vertical intervals. As the tower was raised in height, the pipes were extended by connecting another section at the top, and another length of wire (bell cord)

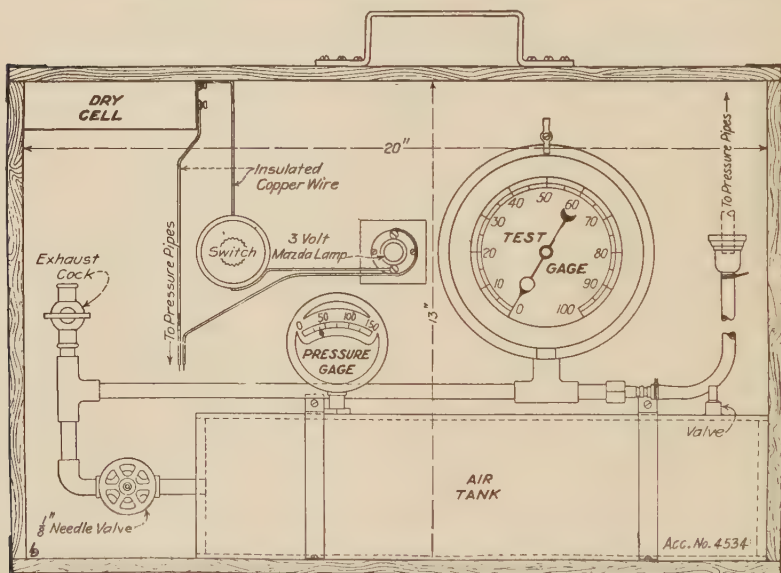


FIG. 104.—Registering apparatus for Goldbeck pressure cells.

This apparatus, consisting of compressed-air tank, pressure gages, electric battery, and light with flexible connections for the pressure pipes, was carried around from place to place in a box not much larger than a suitcase.

was spliced on and threaded through the one pipe. The tower, surrounded by the soft core, was guyed at intervals to hold it in place.

In taking the readings, a portable gage box (Fig. 104) was taken out to the tower and connected to one of the pipes from which the cell to be tested was suspended, the pipe being connected to the pressure tank and the wire to the indicator light. A plug was removed from the end of the other pipe and a light "shot" of compressed air was admitted to the first pipe to dis-

place any water which might have accumulated. It was only necessary to force this water out of the way so as to admit air to the cell, since the weight of a water column (if any) in the second pipe would register on the pressure gage and, therefore, would not affect the correctness of the reading; as a matter of fact, little trouble with water was encountered. The plug was then replaced in the end of the second pipe, and the compressed air was admitted slowly to the cell, until the movement of the diaphragm broke contact and put out the light in the gage box. At

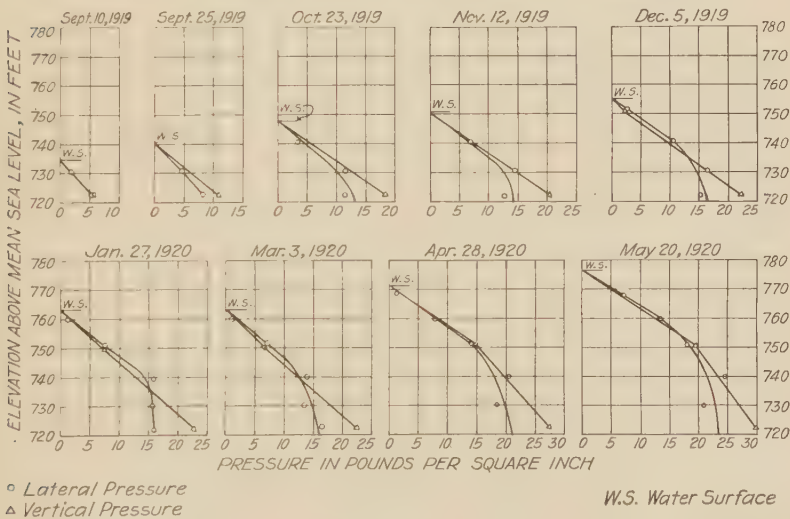


FIG. 105.—Pressure diagrams Germantown core.

Showing relation between vertical and lateral pressures at various dates and under different conditions of loading (see Fig. 107).

that instant the pressure gage indicated the core pressure on the diaphragm. The movement of the diaphragm necessary to break contact (about 0.0001 in.) is so slight that the light may be put out and lighted repeatedly, by proper manipulation of the feed and exhaust valves, without changing the reading of the pressure gage, thus showing that the slight movement of the diaphragm does not disturb the core.

A series of readings at Germantown, covering the period from Sept. 10, 1919 to May 20, 1920, are shown in Fig. 105.

These tests show that after a few weeks the core material begins to consolidate (as indicated by the fact that the lateral

pressures are noticeably less than the vertical pressures at the same elevations) and that as time goes on the difference becomes greater, until after a few months the lateral pressures in the lower parts of the core are only about two-thirds to one-half the vertical pressures. This is proof that the core at those points is losing its fluid properties and that consolidation is taking place. These conclusions are confirmed by later examinations of exposed cores, as will be mentioned.

These nine series of readings at Germantown, covering a period of 8 months, were very satisfactory. Then things began to happen. The dam had reached a height of from 60 to 70 ft. and was being built up at the rate of about 6 or 8 ft. per month. It became impossible to obtain further readings on some of the lower cells because air could no longer be forced through the pipe to the cell. This plugging of the pipe was due, in some cases, to the bunching of the insulation on the wire or at the splices, and, in others, to an accumulated deposit of dirt and flakes of galvanizing. When the length of this small pipe is considered (70 to 80 ft. in the case of the lower cells), this latter trouble is not surprising, although it was overlooked at the start. The use of larger pipe, more careful cleaning of the inside of the pipe, and the construction of a trap at the bottom of the pipe to catch the dirt, corrected these troubles in later installations. Some of the pipe joints then began to leak air, and, about that time, the upper part of the tower showed signs of distress, due probably to movement in the upper (partly fluid) portion of the core or to the settlement of material on the guys. This movement of the partly consolidated portion of the core was demonstrated by sinking a cast-iron ball into it, marking its position by a buoy, and checking that position from time to time. This simple test gave positive evidence that, in the earlier stages of consolidation, there is often some movement, or surging, of the semi-fluid core. Such movement, in itself, is of little consequence, except that it must be given consideration in cases where it is desired to construct a permanent tower or shaft within the limits of the core. Difficulties with such towers or shafts have been experienced in other hydraulic-fill dams, due no doubt to this core movement. Thus, the pressure cell tests at Germantown, following the period covered by the readings shown in Fig. 105, were of interest, principally in revealing defects to be corrected in future installations. The Englewood and Lockington installations were too

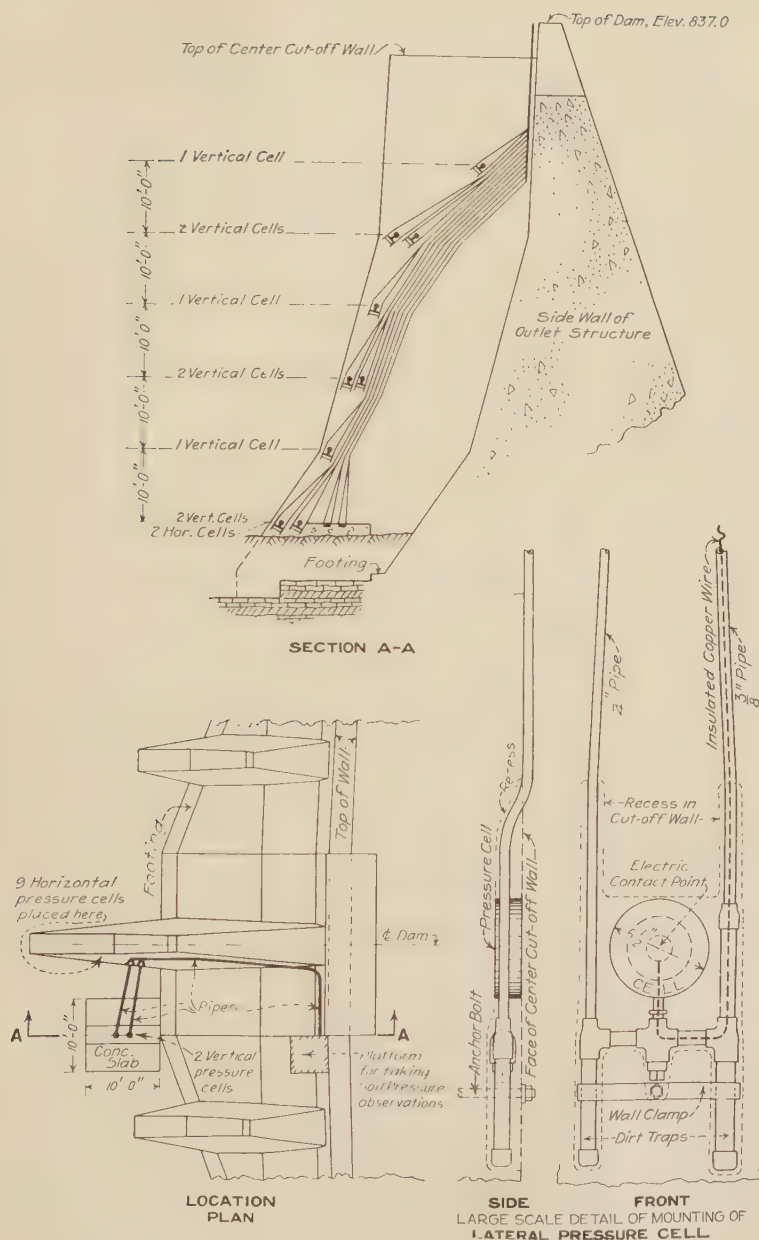


FIG. 106.—Improved installation Goldbeck pressure cells.

This was the installation worked out for Taylorsville dam after experience at several other places. The cells and pipes were fastened securely to concrete footings or walls, and duplicate cells were installed at several elevations to give a check on the readings. Dirt traps were provided at the bottom of the pipes as shown in the lower right-hand view.

far along to be corrected by the time the Germantown troubles had been analyzed. The readings obtained at these places confirmed the conclusions reached from the Germantown tests, but little additional information was secured.

At Taylorsville, full advantage was taken of the experience gained at the other dams, and a much better installation was made. In this case, the cells were fastened to the side of a concrete cut-off, on the back of a high retaining wall forming a part

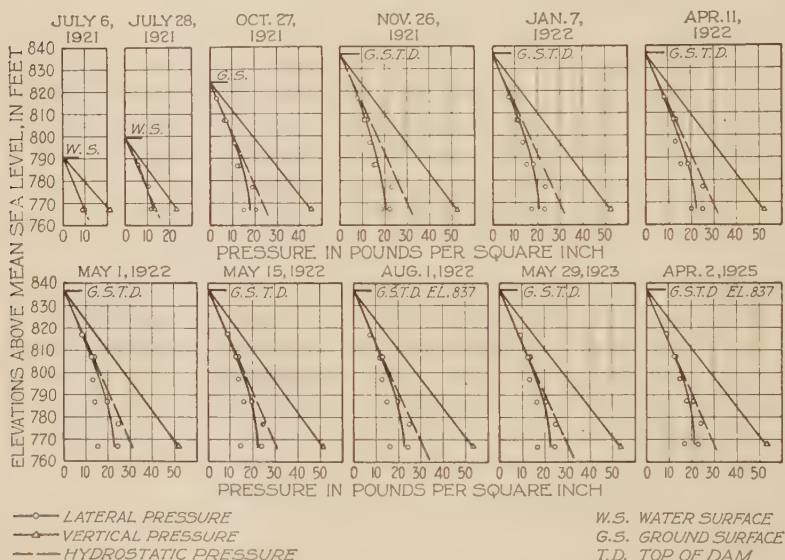


FIG. 107.—Pressure diagrams Taylorsville core.

Showing relations between vertical, lateral, and hydrostatic pressures at various dates and under different conditions of loading. Note that there is little change in these pressures since the dam was completed $3\frac{1}{2}$ yr. prior to the last reading, the lateral pressure being about 40 per cent of the vertical pressure and about 70 per cent of hydrostatic pressure for the same depth.

of the outlet structure. Larger pipes were used, which were fastened securely to the same wall, and instead of joining up the pipe in sections as the dam was raised, the complete installation was made at the start. At the pipe joints, special care was taken to secure a permanently air-tight joint. Dirt traps were provided at the bottom of all the pipes. Figure 106 shows this improved installation.

Cells in vertical position, to measure lateral pressures, were set at 10-ft. vertical intervals as before, but in this case two cells

were set at the bottom and at the 20-ft. intervals, in order to check the readings of one against the other, at those points. Cells to measure the vertical pressures were set at the bottom only, because of the difficulties of making a secure installation in horizontal position at the higher elevations, except at points where the vertical pressure would be affected by friction against the wall. Figure 107 gives the results of readings at Taylorsville to date.

It will be noted that the two cells at the 20-ft. vertical intervals check each other very closely, except at the bottom, where consolidation has taken place to the extent that the lateral pressures are only about 40 per cent of the vertical pressures. This is an indication that the pressure-cell readings are fairly reliable. It might be expected that when consolidation has reached the point where the core is practically a solid, actual lateral pressure might vary at different points to the extent indicated by the readings on the lower cells. The fourth set of readings (Nov. 26, 1921) were taken after the completion of the dam to its full height. The section of the dam in which the cells were set was built up from Elevation 767, where the lowest cells are located, to Elevation 837, the top of the dam, during a period of 6 months; during 1 month the core was raised 33 ft. It is apparent that the core had reached a state of consolidation on Nov. 26, 1921, beyond which the change is very slight. It may be that after construction is stopped, and no further weight is added, there will be no change in the pressure on the cells unless the equilibrium is disturbed. Very likely, the condition represented by the last five or six diagrams, where lateral pressures are from 40 to 50 per cent of the vertical pressures, is normal for well consolidated material of that kind. It is not known whether that ratio has been determined for such materials, but 40 to 50 per cent seems reasonable when one considers that for metals it is supposed to be about 30 per cent.

The Taylorsville method of installation is apparently satisfactory. The results to date have every indication of being reliable; they check with the readings at Germantown, as shown in Fig. 105, and they appear reasonable in the light of examinations of the cores in place, discussion of which will follow.

It is evident from the data secured, that properly graded core material need not be treated as a perfect fluid even after a few weeks of settlement, and that after it has been in place for a few

months, the lateral pressure is only about 50 per cent or less, of the vertical pressure at the same depth. It is believed that this may be accepted as a fact, to be kept in mind in the future design of hydraulic-fill dams.

Ball and Rod Tests.—Penetration tests with a 6-in. cast-iron ball, and with iron rods, were made at all the dams as the work progressed. The value of the ball test lies in the fact that it has been used at other hydraulic-fill dams and therefore it gives the opportunity to make comparisons with cores of other dams, in addition to giving a check on rates of consolidation from day to day. A disadvantage of the ball test is that core material which is only slightly consolidated will support a 6-in. cast-iron ball, so that it never gets down into the more stable material of the core. Several tests were made at the Conservancy dams to see if the cast-iron ball would continue to settle in the core after it had apparently come to rest. It was found in every case that after the first minute there was no further settlement worth mentioning, even over a period of several days.

Penetration tests with a rod or pipe are valuable in detecting the presence of gravel or sand in the core, or to reveal other encroachments of the coarser materials into the core zone. A rod may be forced much farther down into the core than the cast-iron ball will penetrate, and thus gives opportunity to explore the material which has become well consolidated. Forcing down a rod to refusal gives an opportunity to compare rates of consolidation from day to day. The rod commonly used at the Conservancy dams was a $1\frac{1}{2}$ -in. pipe 20 to 30 ft. long, which was operated by two men in a boat. While the same two men, after getting accustomed to this work, would obtain results from day to day that were fairly comparable, it is evident that rod tests on one job cannot very well be compared with those on another, because of the personal equation having such a strong influence on the results. For making comparisons between different jobs, therefore, rod tests are of doubtful value, but as a means of obtaining quick information as to what is going on at any one particular job, they are almost indispensable.

Core Drainage.—There is a difference of opinion as to how the surplus water escapes from the core. Experience at the Conservancy dams indicates that this process is more rapid than could occur by ordinary filtration action. It is very likely that some of the water drains out laterally, but there are indications that

the greater quantity is displaced and forced up, vertically, by settlement of the solids and by pressure due to the superimposed material. In many places, where pumping had been discontinued temporarily, innumerable little springs might be seen in the bottom of the core pool, where water was being forced up by piping. Figure 108 is an illustration of this at one of the dams, where the core pool had been drained preparatory to topping the dam.



FIG. 108.—Core springs Lockington dam.

Showing how the core material gives up its water by vertical piping.

There is further evidence that comparatively little of the water in the core material escapes laterally. While the dams were being built, seepage water was always in evidence at the toe of the porous slopes. This flow was greatly diminished at times when the dredge pumps were shut down and the level of the core pool had dropped one or two feet. During the construction of hydraulic-fill dams in the arid west, vegetation will grow at the foot of the slopes while hydraulic fill is in progress, but as soon as

the work is discontinued, the vegetation will die for lack of water, the explanation being that along the edge of the core pool, immediately below the surface, is a strip of porous slope material not yet silted up by the core; as soon as the water surface drops below this unsilted material, little water escapes through the slopes, and the core pool holds the remainder of the water for a long time. The little springs are still in action, however, and the consolidation of the core goes on, forcing the surplus water to the surface, as illustrated in Fig. 108. It is difficult to explain the rapid consolidation of the Conservancy cores in any other way.

Topping Off the Dam.—When a hydraulic fill gets to the point where its width is less than 100 ft., it becomes difficult to maintain the core pool intact, with pumping equipment of the size used here, and this becomes more and more difficult as the width of the fill decreases.

At the Conservancy dams the spillway elevation was from 12 to 16 ft. below the tops of the embankments, and up to about that point the embankments were wide enough so that the core section could be maintained. Shortly after the spillway elevation had been reached, however, it became necessary to modify the regular hydraulic-fill routine as far as maintaining a separate core section was concerned. While it was not absolutely essential to maintain a definite impervious section more than a few feet above spillway level, it was desirable nevertheless for the embankment to be reasonably impervious all the way to the top.

The simplest methods of topping off the dams were employed at Taylorsville, because there the material was of such nature that the mixture as it came from the dredge pipe was fairly impervious without any re-sorting. It was only necessary there to keep this top material well mixed as it was laid down, and to control the waste water so that it would not break over the slopes. This latter requires more and more careful watching, of course, as the top of the fill is approached. Instead of using the two discharge lines, one on either side of the fill, one line laid along the center was substituted. The height of lift was reduced somewhat, and the upper layers of the fill were placed by starting at the far end and backing away, taking off one length of pipe at a time. Low levees were then thrown up along the edges of this new layer, thereby working over the material to some extent and helping to mix it more thoroughly, and another layer was built up in the same way, by starting at the far end and backing away

as before. At the very last, extra material thrown out into the levees along the shoulders was used for grading and shaping up for the roadway on top of the dam.

At the other dams where a large surplus of clay was not available, as it was at Taylorsville, the topping off was not quite so simple. At Germantown, for example, when the point had been reached where it was decided to abandon the maintenance of the separate core section, the pumping was discontinued for a few days while the small dragline machine, which had been used for throwing up the beach levees, excavated a trench to the depth of several feet, out of the core section, along the entire length of the dam. This material was used to build up levees on either side at the edge of the slope. Care was taken so to mix the material in taking it out, that the levees thrown up in this way would be both stable and impervious, and at the same time the material left in the bottom of the trench was well mixed up, so as to break up any possible strata of pervious material which might have worked its way across the core where it was so narrow.

After this trench had been completed, pumping was started again with borrow pit material selected to yield about 50 per cent clay and 50 per cent gravel. One discharge line was laid along the center, and the trench was filled nearly to the top in this way, starting at the ends of the dam and working toward the center. The dragline machine followed up the dredge pipe as the fill proceeded, and again dug out a trench along the center portion, mixing the material to the extent required and casting it up into levees on either side. Then the center trench was filled again by pumping, and so on until the dam was finally completed.

At Huffman the method was used of raising the upper part of the dam in very low lifts, usually limited to between 6 and 12 in. in thickness. This meant that the pipe lines had to be extended or shortened rapidly, and great care had to be exercised in controlling the waste water, so that it would not break over the slopes. Eventually, however, it was impossible any longer to maintain a core section, and the upper 12 ft. of the fill was made by following the methods used at Germantown, except that the final lift was made by working out from the center of the dam, instead of backing in towards the center as was done at Germantown. The dragline machine kept just ahead of the pipe line, reaching

out and picking up material from under the pipe discharge, and using it to build up the levees. At the other dams, methods of topping off were similar to these.

The plans provided for a roadway along the top of each of the dams. In finishing off the embankment, it was attempted to leave a surface which would be suitable for use as a roadway until such time as traffic over the dams might warrant the use of hard surfaced roads. In several cases, however, it was found that the material as laid down, which apparently contained sufficient fines to give a fairly impervious mixture, did not have sufficient binder material to make a good road surface. It was necessary in those cases to bring in clay to supply the necessary binder material, and this was spread in thin layers, harrowed into the surface, and rolled, until a satisfactory road surface was obtained. Necessary gutters were constructed along the sides, and the surface drainage was taken care of either by pipe drains, or open drains, down the slopes, spaced about 400 ft. apart.

Finishing and Planting Slopes.—The matter of keeping the slopes trimmed to line and grade was usually taken care of as the fill was brought up. The dragline machine, or the men throwing up the levees, had time to do this as the work proceeded. It was usually necessary to go over the slopes again for a final trimming after the hydraulic fill was entirely completed. The original plans and specifications required that the entire surface be covered with a 12-in. layer of top soil, and seeded to grass in order to protect the slope from erosion. Later studies, however, showed that a satisfactory stand of grass could not be maintained under those conditions, as the slope material in the dams was so free draining that enough moisture would not be held to keep ordinary grass alive. At one of the dams the lower part of the downstream slope was given this top soil covering on which it was possible to maintain a satisfactory sod because of the flat slope. At the other dams, however, the use of top soil on the slopes was given up entirely. At Lockington there were enough cobbles and small boulders in the borrow-pit material, so that by raking them out as the fill was built up, a slope covering of clean cobbles approximately a foot in thickness was secured (see Fig. 109). This was the most satisfactory of slope treatments, but unfortunately the necessary surplus of cobbles was not available at the other dams. Even at Lockington the upper part of the slope had to be finished in another way.

Germantown was the first dam to be completed, and there many experiments were made with various grasses and shrubs which might be grown under such conditions as were presented by these dam slopes. Strips several feet wide, up one side of the embankment and down the other, were staked out and planted with different things so that the various plantings would be exposed to exactly the same conditions, so as to learn what, if any, difference in treatment might be required on the sunny or the shady side of the slope. Out of these experiments came the



FIG. 109.—Cobble slope covering on Lockington dam.

A surplus of small boulders and cobbles raked out of the fill were used to cover the slope of the dam below the upper berm to a depth of about 1 ft.

conclusion that sweet clover, and Japanese honeysuckle, were the two things that would grow best on these slopes, and furnish the necessary protection against the action of the elements. It has been found, however, that after a year or two of sweet clover, the resulting inoculation of the soil, and the nitrogen supplied, makes it possible to obtain a good stand of alfalfa, which is a still better slope covering, and eventually will drive the sweet clover out.

On the downstream slopes of the dams the only protection required was against rain wash. Clean gravel slopes, although very porous, were badly eroded by hard beating rains, whereas a slight growth of vegetation seems to give the necessary pro-

tection and break up the tendency for water to collect in rivulets and corrugate the slopes.

The upstream slopes were paved for a certain distance up from the bottom. Large floods which would fill the basin to near the top would occur very seldom, and the water surface would remain at these higher elevations only for a few days at a time, so it was decided that while substantial protection against wave wash was required on the lower part of the slope, a good growth of vegetation would give sufficient protection to the upper part. Sweet clover made a satisfactory growth by simply being sown broadcast over the slopes, although it helped considerably to scatter a light covering of top soil over the slopes at the same time the sowing was made. Sweet clover being a biennial must be sown on two successive years. This has been replaced with alfalfa. Honeysuckle roots were planted at intervals of about 10 ft. and it was found best to surround these roots with a shovelful of top soil at the time they were planted.

It has been mentioned heretofore that the surface drainage from the roadways along the tops of the dams, was carried down the slopes at intervals of about 400 ft. This drainage system also afforded the necessary facilities for draining the slopes themselves. The berms afforded the opportunity to collect the drainage at points along the slopes and lead it to catch basins or inlets which were connected with the main slope drains. At Germantown and Huffman, where there was sufficient rock available, paved gutters were carried straight down the slope. These open drains had the advantage of being easy to keep clean and of being free from danger of clogging. At Lockington it was only necessary to carry the surface drainage from the road down to the first berm, where the cobble surface of the slopes began. Here it was discharged on to the cobble slope by means of a small apron to spread the flow. Below that point slope drainage was not necessary. At Englewood and Taylorsville pipe drains varying in size from 6- to 10-in. diameter, the larger sizes at the bottom, were laid up the slopes and buried deep enough to afford them protection from breakage and from the effects of frost.

Settlement. Records of the amount of settlement were made at two of the dams as soon as the fills were finished. Stakes were set at regular intervals along the top, in such position as not to be disturbed by frost or traffic. Measured settlement

after 6 months, at Germantown, showed a uniform relation to the height of fill at each point, and it was almost exactly one-fourth of 1 per cent in each case. After 18 months this settlement amounted to one-third of 1 per cent, which also was uniform at each point. The depth of fill at these points varied from 32 to 101 ft. below the stakes. At Huffman the settlement after an 8-month period varied from one-fifth of 1 per cent to one-half of 1 per cent, after a period of 17 months. It is safe to say that the maximum settlement after completion of a well constructed hydraulic fill dam is not likely to exceed one-half of 1 per cent.

Costs.—Following are cost figures showing the itemized costs of hydraulic fill at the five dams. These are costs of the whole operation, including borrow pit excavation and transportation, which have been discussed as separate operations in Chaps. V, VII, and IX, costs for which have been given there. In each case coal is included under "Supplies," but electric power is shown as a separate item. It will be noted that the labor item at Germantown is higher than at the other dams. This is because of the fact that the overland haul for all materials and supplies at Germantown increased the cost of all work there. Plant depreciation is higher at Germantown also, partly because of this additional cost of hauling of the equipment in to the job and out again, and also because the quantities were smaller at Germantown and the period of work was shorter.

The low power cost at Englewood, as compared with the other jobs, is probably due to the fact that the quantities handled were so much larger than at the other dams, and there was such a wide distribution and use of electric power on that job that its use could be distributed to much better advantage.

During the period of this construction, labor was being paid from 40 to 46 cts. per hour; dragline operators from \$200 to \$278 per month; locomotive runners 50 to 60 cts. per hour, firemen 40 to 56 cts. per hour, brakemen 40 to 50 cts. per hour, oilers 40 to 56 cts. per hour, pump runners 40 to 47 cts. per hour, monitor men 50 to 65 cts. per hour, all men on an hourly rate being given 11 hr. pay for 10 hr. work (time and a half after 8 hr.).

The quantities are based on actual measurements to neat lines of the theoretical section. The costs include trimming and other incidental work, and all field overhead.

COSTS OF HYDRAULIC FILL EMBANKMENT

		Unit cost, per cubic yard	Per cent of total
Germantown Dam, 795,900 cu. yd.			
Superintendence and overhead.....	\$ 32,458.78	4.1	4.8
Labor.....	313,089.70	39.4	46.7
Supplies.....	130,006.43	16.3	19.3
Power.....	79,457.89	10.0	11.8
Plant depreciation.....	116,732.16	14.7	17.4
Total.....	\$ 671,744.96	84.5	
Englewood Dam, 3,401,500 cu. yd.			
Superintendence and overhead.....	\$ 112,354.37	3.3	4.5
Labor.....	1,174,868.56	34.6	47.7
Supplies.....	666,966.77	19.6	27.0
Power.....	192,322.90	5.7	7.8
Plant depreciation.....	320,048.43	9.4	13.0
Total.....	\$2,466,561.03	72.6	
Lockington Dam, 795,200 cu. yd.			
Superintendence and overhead.....	\$ 29,852.61	3.6	5.0
Labor.....	241,508.74	30.5	42.2
Supplies.....	115,784.80	14.6	20.3
Power.....	122,607.40	15.3	21.2
Plant depreciation.....	64,899.75	8.1	11.3
Total.....	\$ 574,653.30	72.1	
Taylorsville Dam, 908,500 cu. yd.			
Superintendence and overhead.....	\$ 34,348.86	3.8	5.2
Labor.....	297,819.64	32.8	44.6
Supplies.....	132,170.25	14.5	19.7
Power.....	154,784.36	17.0	23.2
Plant depreciation.....	49,255.09	5.4	7.3
Total.....	\$ 668,378.20	73.5	
Huffman Dam, 1,349,800 cu. yd.			
Superintendence and overhead.....	\$ 49,922.91	3.7	5.1
Labor.....	475,473.66	35.2	48.8
Supplies.....	162,404.06	12.1	16.8
Power.....	146,162.96	10.9	15.1
Plant depreciation.....	140,833.52	10.2	14.2
Total.....	\$ 974,797.11	72.1	

San Fernando Dam.—This hydraulic-fill dam was constructed near Los Angeles, Calif., by the Los Angeles Aqueduct Company. It has a maximum height of 145 ft., is 1,700 ft. long, and contains 2,000,000 cu. yd. The material was gravel, clay, and silt—about 20 per cent of fine material. Hydraulic giants, with 2-in. nozzles and fed through 4-in. pipes at 140 to 160 lb. pressure, loosened the material and washed it through a natural channel to the pool at the dam site. The maximum distance it was carried was about 3,000 ft. At the dam the material was pumped by 12-in. centrifugal pumps to the top of the embankment. In the sluice trench a minimum flow of 12 sec.-ft. was maintained and about 8,000 cu. yd. of material was handled per 24-hr. shift by the two pipe lines. A crew of six men handled the work.¹

Quemahoning Dam.—Fourteen miles south of Johnstown, Pa., the Cambridge Steel Company constructed a hydraulic-fill dam for water storage. This structure is 950 ft. long on the crest, has a maximum height of 95 ft., and side slopes of 4 to 1 on the downstream side and 3 to 1 on the upstream side. A concrete corewall was built in a cutoff trench which extends to bed-rock along the centerline of the dam. This corewall was placed 10 to 27 ft. in the shale rock and extends 10 ft. above the rock surface. It is 8 ft. wide at the rock surface and 4 ft. wide at the top.

A concrete outlet conduit 30 by 21 ft. pierces the dam, and at one end is a concrete spillway 250 ft. long.

The material for the dam was sluiced through wooden flumes into the structure. The main flume was 2 ft. wide and $1\frac{1}{2}$ ft. deep and was lined on the bottom with $\frac{1}{4}$ -in. steel plates. The grade of this flume was 6 per cent. Hydraulic giants with 4- and 5-in. nozzles, working under 75- to 110-lb. pressure, sluiced the material from the borrow pit. The material consisted of a mixture of coarse gravel, fine gravel, and clay. Water for sluicing was furnished by two 14-in. centrifugal pumps delivering 5,500 g.p.m. against a head of 500 ft. To control the flow of the material as it left the flume, sheet-iron plates were set on edge to form channels, and the material could be directed where it was needed.

¹ *Eng. Record*, July 11, 1914.

The total amount of fill placed in 22 months by three giants operating in two 10-hr. shifts, was 526,000 cu. yd. The maximum month's work was 58,000 cu. yd.¹

Wichita Falls Dam.—Wichita County Water Improvement District No. 1, Texas, constructed a large hydraulic-fill dam about 40 miles from Wichita Falls. This dam is 7,500 ft. long on the crest, has a maximum height of 100 ft. and contains 1,500,000 cu. yd. of material, of which 1,285,000 cu. yd. was hydraulic fill. Practically all of the material for the dam was dredged from the river valley above the dam. The material is a fine sand containing about 25 per cent clay and very fine sand suitable for core material.

Six circular reinforced concrete conduits, each 7 ft. in diameter, were constructed to pass the river flow during construction and to serve as permanent outlets.

A large floating hydraulic dredge was built to excavate the material for the fill. The hull of this dredge was 111 ft. long, 42 ft. wide, and 9½ ft. deep. It was equipped with two wooden spuds, each 26 in. square, and a 75-ft. suction ladder. The main pump had a 20-in. suction and discharge pipe. It was electrically operated, being direct-connected to a 1,600-hp. motor and run at 360 r.p.m. The pump runners were made of cast-steel and were from 54 to 64 in. in diameter. Manganese-steel pump shells were used which had cast-iron renewable liners.

The discharge line was made up of sections of 20-in., No. 10 gage, riveted-steel pipe. The line was floated on pontoons to the shore, and then carried on the ground or on trestles. All pipe was rotated at intervals to get even wear; the average life of a pipe was about 600,000 cu. yd.

The material dredged was easily handled, as it was uniform in grade and contained no oversize stone. The average velocity in the pipe line was from 10 to 15 ft. per second.

Two methods were used to confine the material to the desired slopes and to retain the core pool. At first timber bulkheads were built up along the slopes and parallel to the center line of the dam. Later dragline excavators were used to build up levees to confine the core pool. The core width was controlled by shear boards, when necessary. These were placed near the ends of the discharge pipe so as to deflect the materials as desired.

¹ *Eng. Record*, Feb. 15, 1913.

The daily capacity of the dredge was 10,000 cu. yd. For the first 4 months of pumping the output averaged 200,000 cu. yd. per month.¹

Additional examples of hydraulic-fill construction are given in the discussion of levee embankments (Chap. XI), and further data on pumping may be found in the chapters on hydraulic sluicing and dredging.

¹ *Eng. News-Record*, Vol. 91, No. 25, Dec. 20, 1923.

CHAPTER XIV

SEMI-HYDRAULIC FILL

The distinction between hydraulic and semi-hydraulic fill has been given in the preceding chapter. The semi-hydraulic method of building embankments is used principally where the borrow-pit materials do not contain the proper proportions of coarse and fine materials for a tight structure, or where other conditions are not favorable for regular hydraulic-fill methods. By means of the semi-hydraulic process it is easier to bring to the embankment materials from different pits or different parts of a pit and place them in proper proportions so that when sluicing is started the fines may be conveyed to the core. Less water is needed for semi-hydraulic work than for true hydraulic fill, and ordinarily less pumping equipment and pipe lines are needed.

The usual method of building a semi-hydraulic fill is: first, the excavated material is hauled in trains of dump cars or by wagons from the borrow pit to the site of the embankment; then the material is dumped so as to build up embankments along the toes of the fill on each side of the center line, these embankments, usually extending from end to end of the structure, being kept far enough apart to leave room for the core; as this material is being dumped hydraulic giants are used to work it over and settle it, at the same time washing the fines to the center to form the impervious core.

The foundation for a semi-hydraulic-fill dam must be prepared in the same careful manner that foundations are made ready for other earth fills. All brush, vegetation, and humus should be removed from the area to be covered by the fill, and some form of cut-off constructed. Sometimes a cut-off trench is excavated, which is backfilled with selected puddled material. Often concrete core walls are built in the cut-off trenches, and in some dams, the core wall is carried nearly to the top of the finished structure.

To facilitate the building up of the embankment, trestles usually are constructed along the fill and the material is dumped from these trestles. When the embankment reaches the top of

a line of trestles, another line is erected from which to build the next lift. Trestle work may be dispensed with, in which case the embankment is brought up by dumping from tracks laid on the ground and jacked up as the filling progresses. Dragline excavators have been used to advantage to build up the sides of the embankment, handling the material from dumped piles on the original ground level to lifts as high as 40 to 50 ft. Practical considerations will govern the choice of method for depositing the material; these considerations are about the same as those affecting the construction of large railroad fills, and reference should be made to Chap. XI for a discussion of these matters.

When depositing the material in the dam, care should be taken (where there is a variation in the size and quality of the material) to place the coarser material in the downstream portion of the embankment and the finer material in the upstream portion.

Various methods and plant layouts are used to sluice the fine material to the center. Usually the sluicing giants are located on the sides of the fill or are mounted on trestles in the central portion of the dam near the sides. Sometimes hulls or barges which float in the core pool carry the sluicing monitors. In any case, the sluicing is carried on in such manner that the coarser material will remain near the outer slopes and the finer material is carried toward the center, the finest material being deposited in the core pool or settling pond so as to form the impervious core. To avoid stratification in the core, the quantity and pressure of water and the direction and point of application of the stream are regulated according to the nature of the material. Sometimes mechanical mixing of the core materials after deposition is used as an added precaution. The material of the upstream slope is not washed clean of fines as a certain percentage of clay and sand there is desirable. The bottoms of the core pools are kept approximately level longitudinally to prevent undue flow of silt to one end.

On long dams, it may be necessary to use a series of core pools separated by temporary cross-dams in case it is not possible to carry the embankment across the valley in one operation. If cross-dams are built they should be of impervious material, and the sluiced core should be carefully keyed into them as the work progresses.

A uniform width and slope of the core may be secured by keeping the water surface of the core pool of uniform width, raising both sides of the embankment at the same rate, and varying the quantity and direction of the sluicing stream. The quantity of water may be regulated at the pumps. The direction of the stream may be regulated by moving the nozzle and by the use of shear boards.

The equipment needed to build a plant for a semi-hydraulic-fill job will consist of the excavating outfit, trestling and tracks, one or more pumps and hydraulic giants, and enough pipe to serve the giants. The excavating plant may be steam shovels, dragline excavators, elevating graders, scrapers, or some special plant. Transportation is nearly always by trains of dump cars, though motor trucks may be used sometimes to advantage.

EXAMPLES OF SEMI-HYDRAULIC FILLS

Somerset Dam, Vermont.—This earth dam, 2,080 ft. long on the crest and with a maximum height of 106 ft., was built by the semi-hydraulic process. The material was excavated by steam shovels and hauled to the toes of the dam by dump cars and then the finer material was washed to the center by hydraulic monitors. Two shovels with $2\frac{1}{2}$ -cu. yd. dippers handled the excavation. The hauling was done by an outfit of ten 19-ton dinkey locomotives and 100 dump cars. The pumping plant for sluicing consisted of two compound duplex steam pumps rated at 750 g.p.m. at 200-lb. pressure and three 60-hp. boilers. A 6-in. supply line was run along each trestle (one on each side of the embankment) with T-fittings every 90 ft. with valves for connecting on lengths of 3-in. rubber sluicing hose, fitted with $1\frac{3}{4}$ -in. nozzles, mounted on temporary wood stands. The material deposited from the trestles was undercut by streams from these nozzles and washed down into position in the center of the dam. Overflow waste water was carried away by an 18-in. concrete pipe leading into the conduit through the dam. The total quantity placed in this dam in two seasons was 1,000,000 cu. yd. (1912–1913).

The Davis Bridge Dam.—This earth dam on the Deerfield River near Readsboro, Vt., is 200 ft. high and contains 1,900,000 cu. yd. of fill. It was built entirely by the semi-hydraulic-fill method.

Preliminary to the construction of the embankment a $22\frac{1}{2}$ -ft. diversion tunnel was driven, part of which was through solid rock. This tunnel was lined with concrete.

The embankment construction followed standard methods in a general way. All material for the dam was excavated in the borrow pits by steam shovels, loaded on cars and hauled to the upper and lower sides of the dam where it was dumped from the dikes and sluiced down. On part of the work, trestles were built along the sides and the dumping was done from these trestles until the fill reached the top of the trestles, after which the fill was widened by dumping and throwing track. Delay in completing the river diversion made it necessary to start placing material before trestles could be built. A log crib was built diagonally across the stream near the upstream toe and then extended near the left bank parallel with the stream some 300 ft. This crib diverted the flow to the left bank and permitted the placing of considerable material in the upper third of the dam prior to river diversion. A shelf was cut along the right bank at an elevation about 50 ft. above the river and dumping started from this shelf was carried out until the toe of the slope reached the top of the crib. In a similar manner material was placed in the lower third of the dam, except that no crib work was used here, but the material was allowed to crowd the river toward the left bank. After the river had been diverted through the completed tunnel, the river gap was closed and the entire dike was brought up to the 50 ft. height. Then a 20-ft. trestle was placed on top of the dike and filling continued to the top of this trestle.

The river bed was carefully cleaned up, as well as the foundation for the entire middle third of the dam, and then filling operations continued. A large dragline excavator was used to assist in building up the dikes. It dug a pit alongside the dump track into which the trains could dump quickly. From this pit it handled the material into a dike extending about 30 ft. above its own working elevation. By the use of this machine, much trestle work was eliminated.

All sluicing was done by two 750-gal. centrifugal pumps at 100-lb. nozzle pressure direct-connected to 100-hp. motors. Each unit was mounted on a raft in the central pool. A third stationary pump furnished water to several hose lines which were used in washing down material to provide free dumping space at the track elevation.

On this job standard-gage equipment was used for hauling. Special attention was given to track layouts, and efficient track crews were maintained. The principal items of equipment were: 15 locomotives, 102 dump cars of 12- and 16-cu. yd. capacity, 6 railroad type steam shovels up to 5-cu. yd. capacity, 2 small revolving shovels, 1 dragline machine, a locomotive crane, 3 sluicing pumps, and necessary repair items and machine shop.

About 500,000 cu. yd. of fill was placed in the first season of 6 months, and the additional 1,400,000 cu. yd. in the next season which was about 8 months.¹

Tieton Dam.—The U. S. Reclamation Service built the Tieton dam in the Yakima Valley, Washington, to provide storage for irrigation purposes. This dam is of earth heavily blanketed with rock, approximately 230 ft. high and 900 ft. long on the crest, with a concrete corewall of an approximate height of 330 ft. extending from solid rock to the crest.

The concrete corewall was built first. In the river bed it was necessary to excavate to a depth of 110 ft. to reach bedrock. The excavation tapered on one side of the canyon to 35 ft. depth; on the other side bedrock was exposed. The mining method of stoping, or sinking shafts and working the material from these shafts, was used to excavate for the corewall. The work was handled in three drifts or "floors." The corewall is 5 ft. thick below the original ground surface, and it tapers to 12 in. in thickness at the top of the dam; it is heavily reinforced.

The earth and rock material for the embankment was excavated from the mountain sides by electric and steam shovels. Eight 16-ton steam locomotives hauled the material in trains of dump cars to the dam. The tracks ran on to the slopes of the dam over trestles which were built at intervals in elevation of about 30 ft. As the material was dumped from the trestles, hydraulic giants washed it toward the core pool. The pipe lines to serve the giants were laid on trestles in the core pool. The main pipe lines were laid across the valley and lateral lines extended at right angles from these to such points as were convenient for sluicing. Three or four giants were used to sluice down the material. A pump installed in the pool just below the corewall was used to pump a large amount of the soft, clayey material from the lower side of the corewall to the upper side, leaving a

¹ *Eng. News-Record*, Vol. 92, No. 6, Feb. 7, 1924.

fine-graded sandy material against the downstream side of the corewall and a tight clayey puddle against the upstream side.¹

The Alouette Dam.—The Alouette dam was built to provide a storage reservoir for a hydroelectric development near Vancouver, B. C. It is an earth fill 1,000 ft. long on the crest, with a maximum height of 63 ft. above the streambed. The dam contains about 143,000 cu. yd. of clay and gravel.

All material for the embankment was excavated by steam shovels. The general method of placing the fill was to bring in the material in cars, dump it near the outer slopes of the dam and sluice it down toward the center with hydraulic giants. A giant mounted on a float in the core pool worked the inner face of the clay fill, washing the fine material down into the pool and leaving the coarse lumps on the outer slopes. The clay lumps were very tenacious and did not break up under the nozzles.

Successive lifts of the embankment were started by building up the gravel fills on the outer edges. This was accomplished by dumping the gravel from side-dump cars and jacking up the dumping tracks as the gravel fill was raised until the fill was $2\frac{1}{2}$ to 3 ft. higher than the pool. Then clay was again hauled in and sluiced as before.

The pumping plant, with a capacity of 1,000 g.p.m. at 125-lb. pressure, was installed on the lake shore at the upstream toe of the dam. An 8-in. wood-stave pipe line was carried around the dam and spur lines were tapped into this main line to the giants. Three giants were generally used on each side of the dam, these being shifted as the filling progressed. The nozzles were $1\frac{1}{2}$ -in. diameter.

The tendency of coarse material to get to the core was combatted by the use of vertical screens fastened to floats which were anchored in front of the giants in use. The screens were about 10 ft. high and consisted of 6- by 6-in. reinforcing mesh overlaid with 1-in. mesh "chicken wire" netting fastened to timber framework. The screens were built in sections about 40 ft. long.

The use of giants to spread the material proved economical and had the advantage of thoroughly working over with water all of the clay going into the dam.

On this job progress of filling varied; the best month showed 35,070 cu. yd. placed in 25 days of two 8-hr. shifts. The best day's run was 1,954 cu. yd. (this in two 8-hr. shifts).²

¹ *Successful Methods*, October, 1923.

² *Eng. News-Record*, Vol. 96, No. 17, Apr. 29, 1926.

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